Table of Contents

Section 7

Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Section 7

Inspection and Evaluation of Common Concrete Superstructures

Topic 7.1 Cast-in-Place Slabs

7.1.1 Introduction

The cast-in-place slab bridge is the simplest type of reinforced concrete bridge and was a common choice for construction in the early 1900's (see Figures 7.1.1 and 7.1.2). Sometimes the terms "deck" and "slab" are used interchangeably to describe the same bridge component. However, this is incorrect. A deck is supported by a superstructure unit (beams, girders, etc.), whereas a slab is a superstructure unit supported by a substructure unit (abutments, piers, bents, etc.). A deck can be loosely defined as the top surface of the bridge, which carries the traffic. A slab serves as the superstructure and the top surface that carries the traffic. Even though slabs are defined differently than decks, many of the design characteristics, wearing surfaces, protective systems, inspection procedures and locations and, evaluation, are similar. See Topic 5.2 for further details.

Figure 7.1.1 Typical Simple Span Cast-in-Place Slab Bridge

Figure 7.1.2 Typical Multi-span Cast-in-Place Slab Bridge

7.1.2 Design Characteristics

General

The slab bridge functions as a wide, shallow superstructure beam that doubles as the deck. This type of bridge generally consists of one simply supported span and is typically less than 9 m (30 feet) long. Simple and continuous multi-span slab bridges are also common. The only primary member in a cast-in-place slab bridge is the slab itself.

Steel Reinforcement

For simple spans, the slab develops only positive moment; therefore, the primary, or main tension reinforcement is located in the bottom of the slab. The reinforcement is placed longitudinally, or from support to support, parallel to the direction of traffic. For continuous spans, additional primary reinforcement is located longitudinally in the top of the slab over the piers to resist negative bending moments.

Secondary reinforcement, known as temperature and shrinkage steel, is located transversely throughout the top and bottom of the slab. In simple span slabs, secondary reinforcement is also located longitudinally in the top of the slab. In continuous span slabs, the primary reinforcement is often placed the full structure length, negating the need for longitudinal secondary reinforcement.

Nearly all slab bridges have a grid or mat of steel reinforcement in both the top and bottom of the slab that is formed by some combination of primary and secondary reinforcement (see Figure 7.1.3).

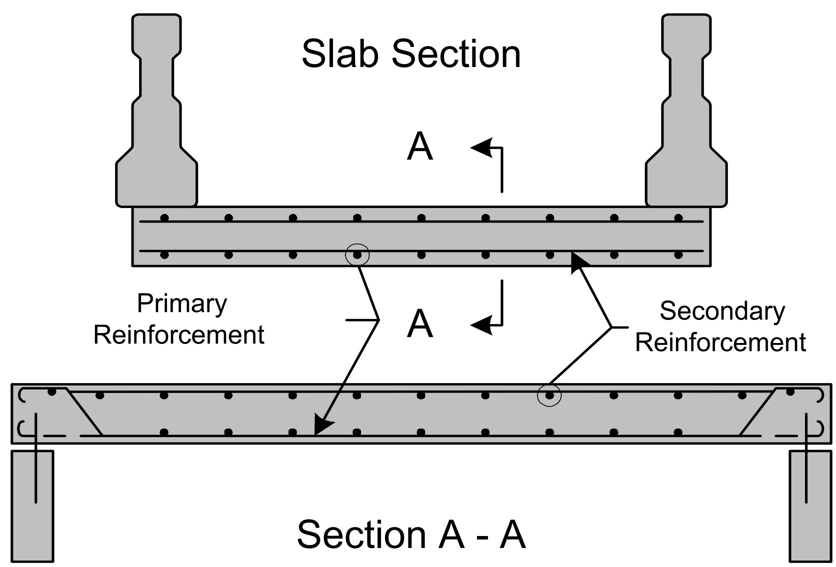


Figure 7.1.3 Steel Reinforcement in a Concrete Slab

7.1.3 Overview of Common Defects

Common defects that occur on cast-in-place slab bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear

- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.1.4 Inspection Procedures and Locations

Inspecting a cast-in-place slab bridge is similar to the procedure discussed in Topic 5.2.6, Concrete Decks, and includes the following specific procedures:

Procedures

Visual

The inspection of concrete slabs for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid “pinging” type sound.

Physical

The physical examination of a slab with a hammer can be a tedious operation. In most cases, a chain drag is used. A chain drag is made of several sections of chain attached to a pipe that has a handle attached to it. The inspector drags this across a slab and makes note of the resonating sounds. A chain drag can usually cover about a 900 mm (3 feet) wide section of slab at a time (see Figure 5.2.8).

If the inspector deems it necessary, core samples can be taken from the slab and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete bridge slabs are caused by corrosion of the rebar. When the deterioration of a concrete slab progresses to the point of needing rehabilitation, an in-depth inspection of the slab is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing

- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

Examine bearing areas for spalling where friction from thermal movement and high edge or bearing pressure could cause the concrete to spall (see Figure 7.1.4).

Figure 7.1.4 Steel Rocker Bearing Supporting Haunched Slab at Pier

Shear Zones

Investigate areas near the supports for shear cracking. The presence of transverse cracks on the underside near supports or diagonal cracks on the sides of the slab indicate the onset of shear failure (see Figures 7.1.5 and 7.1.6). These cracks represent lost shear capacity and should be carefully measured.

Figure 7.1.5 Shear Cracks in the Ends of a Slab Bridge

Figure 7.1.6 Shear Zone on the Underside of a Continuous Slab Bridge Near a Pier

Tension Zones

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the slab. The tension zones are at midspan along the bottom of the slab for both simple and continuous span bridges. Additional tension zones are located on top of the slab over the piers for continuous spans. Cracks greater that 2 mm (1/16 inch) wide are considered wide cracks and indicate extreme bending stresses. Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete (see Figure 7.1.7). Slab bridges which use hooks to develop the primary reinforcement are not as susceptible to debonding due to deterioration of the concrete.

Figure 7.1.7 Delamination and Efflorescence with Rust. Stains on Slab Underside in Tension Zone

Areas Exposed to Drainage

Inspect areas exposed to roadway drainage for deteriorated concrete. This includes the entire riding surface of the slab, particularly around scuppers or drains. Spalling or scaling may also be found along the curbline and fascias (see Figure 7.1.8).

Areas Exposed to Traffic

For grade crossing structures, check areas exposed to traffic for damage caused by collision. Such damage will generally consist of corner spalls and may include exposed rebars.

Skewed Bridges

Examine skewed bridges for lateral displacement and cracking of acute corners due to point loading and insufficient reinforcement.

Figure 7.1.8 Deteriorated Slab Fascia due to Roadway Deicing Agents

7.1.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2). For a slab bridge, these guidelines must be applied for both the deck component and the superstructure component.

The previous inspection data should be used along with current inspection findings to determine the correct rating. Typically, for this type of structure, the deck and superstructure components will have the same rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of slab and the underside. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element Level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a slab bridge, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
38	Concrete Slab – Bare
39	Concrete Slab – Unprotected with AC Overlay

40	Concrete Slab – Protected with AC Overlay
44	Concrete Slab – Protected with Thin Overlay
48	Concrete Slab – Protected with Rigid Overlay
52	Concrete Slab – Protected with Coated Bars
53	Concrete Slab – Protected with Cathodic System

The unit quantity for these elements is "each", and the entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2). Condition state 1 is the best possible rating. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit into a given condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For structural cracks in the surface of bare slabs, the "Deck Cracking" Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a slab element, the "Soffit" Smart Flag, Element No. 359, can be used and one of five condition states assigned.

This page intentionally left blank

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Topic 7.2 Tee Beams

7.2.1 Introduction

The concrete tee beam, a predominant bridge type during the 1930's and 1940's, is generally a cast-in-place monolithic slab and stem system formed in the shape of the letter "T."

The cast-in-place tee beam is the most common type of tee beam. However, precast tee beam shapes are used by some highway agencies. Types of precast tee beams include bulb tee, double tee, quad tee, and rib tee.

Recent technology has also produced the inverted tee beam, a new type of precast tee beam, for short to medium span bridges. Developed in Nebraska, this prestressed concrete beam reduces the weight up to 20% compared to conventional I-beams and eliminates the need for falsework construction.

7.2.2 Design Characteristics

General

Spacing of the tee beams is generally 900 to 2400 mm (3 to 8 feet), center-to-center of beam stems. The depth of the stems is generally 450 to 600 mm (18 to 24 inches). Simple span design was most common but continuous span designs were popular in some regions. A 75 or 100 mm (3 or 4 inch) fillet at the slab-stem intersection identifies this older form of construction (see Figure 7.2.2).

Care must be taken not to describe tee beam bridges as composite. They do not meet the definition of composite, because the slab and stem are constructed of the same material. The slab portion of the beam is constructed to act integrally with the stem, providing greater stiffness and allowing increased span lengths. The tee beam bridge is used for spans between 9 and 15 m (30 and 50 feet). Simple spans are most common; however, there are some multi-span continuous tee beam bridges in use (see Figure 7.2.1).

Figure 7.2.1 Multi-span, Simply Supported Tee Beam Bridge

Figure 7.2.2 Typical Tee Beam with Fillet

The inspector should be careful not to mistake a concrete encased steel I-beam bridge for a tee beam bridge. A review of the structure file should eliminate this problem. If necessary, a dimensional evaluation will show the encased steel beams to be smaller in size.

Figure 7.2.3 Concrete Encased Steel I-beam

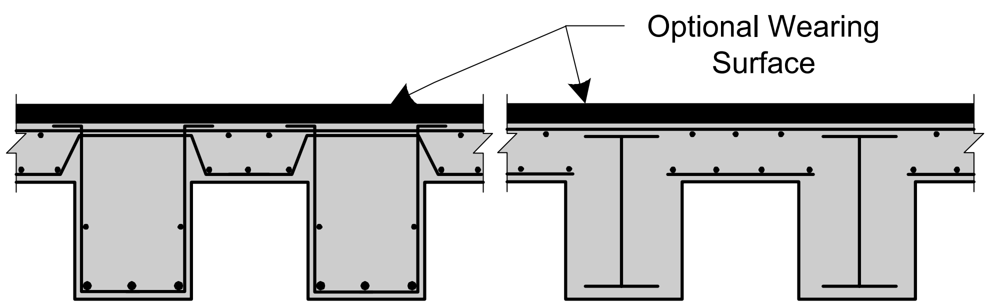


Figure 7.2.4 Comparison Between Tee Beam and Concrete Encased Steel I-beam

Primary Members and Secondary Members

The primary members of a tee beam bridge are the tee beam stem (web) and slab (flange) (see Figure 7.2.5).

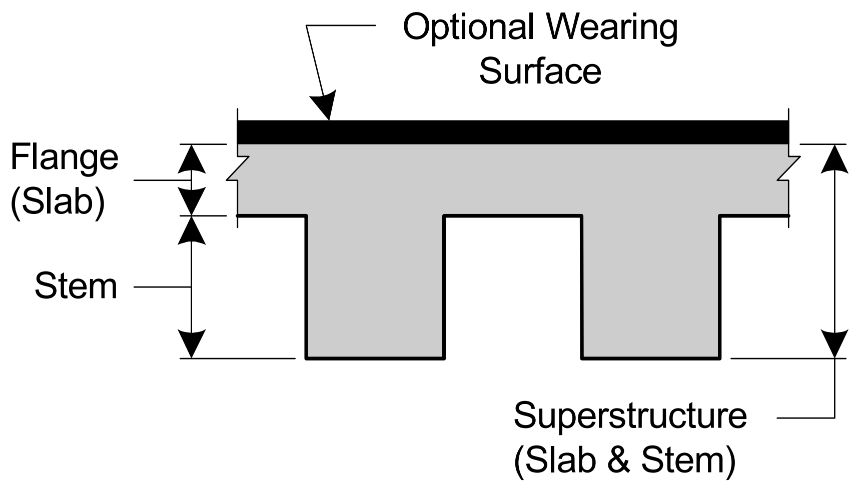


Figure 7.2.5 Tee Beam Cross Section

The only secondary members on a cast-in-place tee beam bridge are the diaphragms, which support the free edge of the beam flanges. Intermediate diaphragms may also be present in longer span bridges and are usually located at the half or third points along the span.

The diaphragms are designed as simple beams and should be inspected for flexure and shear cracks, as well as for typical concrete defects.

Figure 7.2.6 Tee Beam Diaphragms

Steel Reinforcement

The primary (tension) reinforcing steel consists of main tension reinforcement and shear reinforcement or stirrups. The main tension reinforcement is located in the bottom of the beam stem and oriented longitudinally (see Figure 7.2.7). If the concrete tee beams are continuous, there will be longitudinal reinforcement close to the top surface of the slab over the piers. The sides of the stem contain primary vertical shear reinforcement, called stirrups, and are located throughout the length of the stem at various spacings required by design. Stirrups are generally U-shaped bars and run transversely across the bottom of the stem (see Figure 7.2.7). The need for stirrups is greatest near the beam supports where shear stresses are the highest.

The secondary (temperature and shrinkage) reinforcing steel for the stem is oriented longitudinally in the sides (see Figure 7.2.7). The primary and secondary reinforcing steel for the slab portion of the beam is the same as for a standard concrete slab.

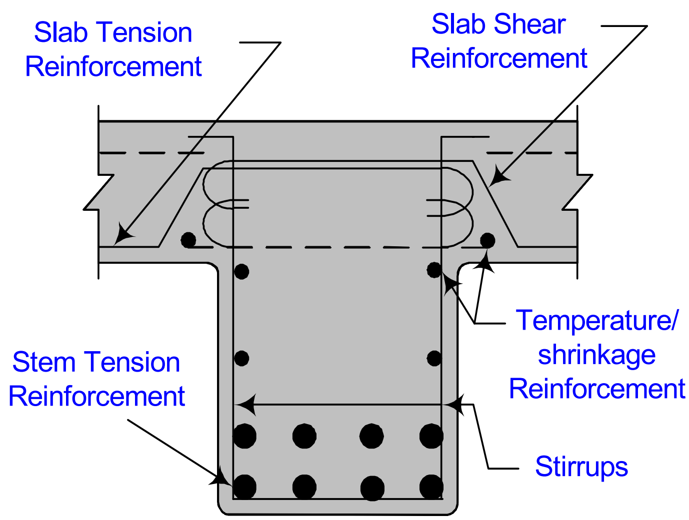


Figure 7.2.7 Steel Reinforcement in a Concrete Tee Beam

7.2.3 Overview of Common Defects

Common defects that occur on concrete tee beam bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.2.4 Inspection Procedures and Locations

Inspecting a tee beam bridge is similar to the procedure discussed in Topic 5.2.6 and includes the following specific procedures:

Procedures

Visual

The inspection of concrete tee beams for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of a tee beam with a hammer can be a tedious operation. In most cases, a chain drag is used. A chain drag is made of several sections of chain attached to a pipe that has a handle attached to it. The inspector drags this across a slab and makes note of the resonating sounds. A chain drag can usually cover about a 900 mm (3 feet) wide section of slab at a time (see Figure 5.2.8).

If the inspector deems it necessary, core samples can be taken from the tee beam and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete tee beams are caused by corrosion of the rebar. When the deterioration of a concrete tee beam progresses to the point of needing rehabilitation, an in-depth inspection of the tee beam is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer

- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

Examine bearing areas for spalling where friction from thermal movement and high bearing pressure could cause the concrete to spall. Check for crushing of the stem near the bearing seat. Check the condition and operation of any bearing devices (see Figures 7.2.8 through 7.2.11).

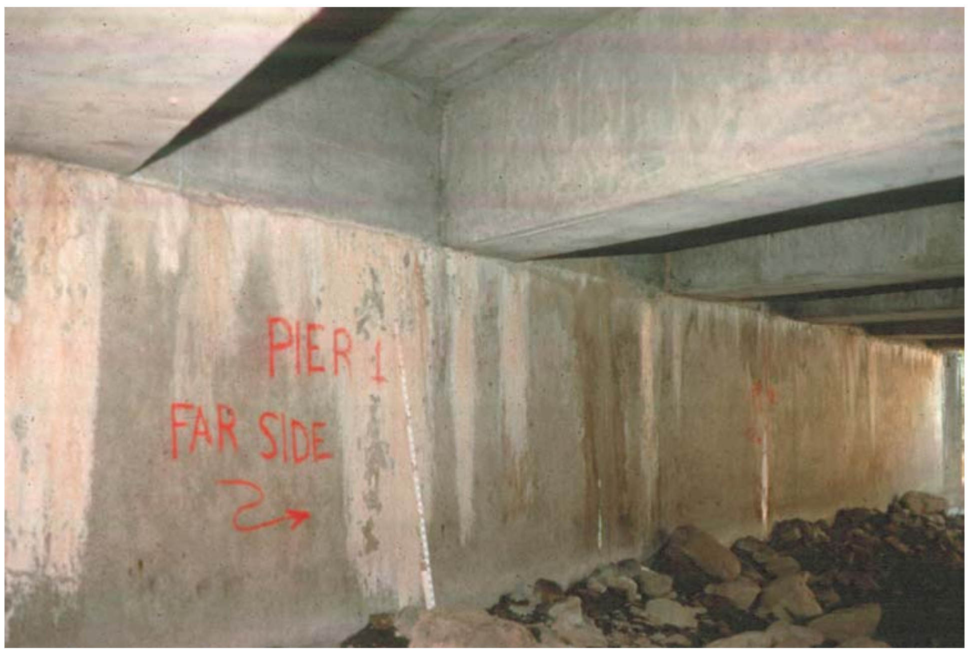


Figure 7.2.8 Bearing Area of Typical Cast-in-Place Concrete Tee Beam Bridge

Figure 7.2.9 Spalled Tee Beam End

Figure 7.2.10 Deteriorated Tee Beam Bearing Area

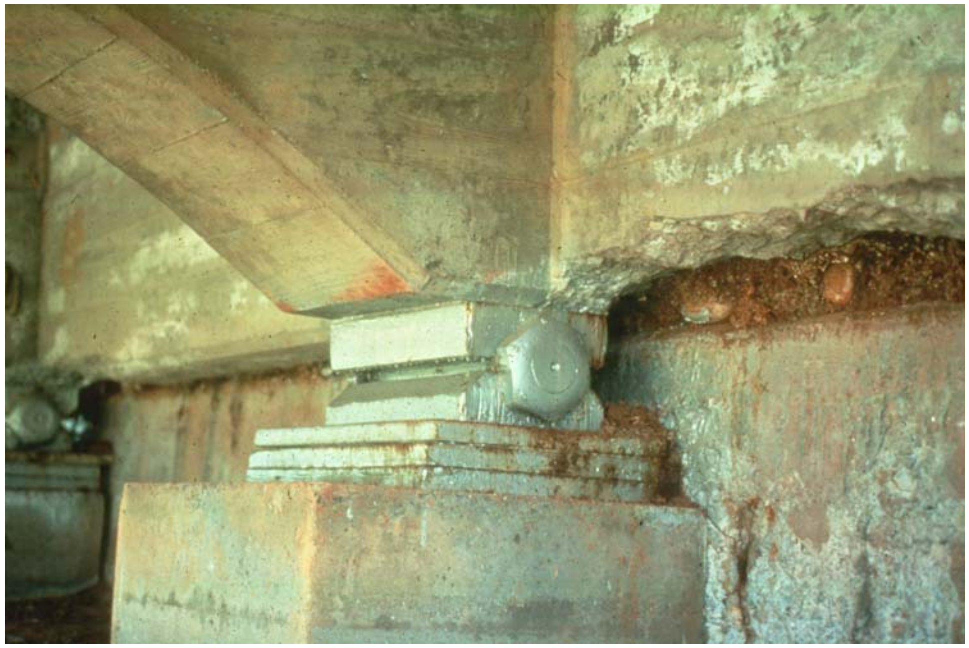


Figure 7.2.11 Steel Bearing Supporting a Cast-in-Place Concrete Tee Beam

Shear Zones

Investigate the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the stems or diagonal cracks on the sides of the stem indicate the onset of shear failure. These cracks represent lost shear capacity and should be carefully measured.

Figure 7.2.12 Shear Zone of Cast-in-Place Concrete Tee Beam Bridge

Tension Zones

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the bottom of the stem (see Figure 7.2.13). The tension zones are at the midspan along the bottom of the stem for both simple and continuous span bridges. Additional tension zones are located on the slab over the piers for continuous spans (see Figure 7.2.14). Cracks greater that 2 mm (1/16 inch) wide are considered wide cracks and indicate extreme bending stresses. Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel (see Figure 7.2.15). In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity (see Figure 7.2.16).

Figure 7.2.13 Flexure Cracks on a Tee Beam

Figure 7.2.14 Flexure Cracks in Tee Beam Slab

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete (see Figure 7.2.15).

Figure 7.2.15 Stem of a Cast-in-Place Concrete Tee Beam with Contaminated Concrete

Figure 7.2.16 Spall on the Bottom of the Stem of a Cast-in-Place Tee Beam with Corroded Main Steel Exposed

Areas Exposed to Drainage

If the roadway surface is bare concrete, check for delamination, scaling, and spalls. The curb lines are most suspect. If the slab has an asphalt wearing surface, check for indications of deteriorated concrete such as reflective cracking and depressions (see Figure 7.2.17).

Figure 7.2.17 Asphalt Covered Tee Beam Slab

Check around scuppers or drain holes and slab fascias for deteriorated concrete (see Figure 7.2.18).

Figure 7.2.18 Deteriorated Tee Beam Stem Adjacent to Drain Hole

Check areas exposed to drainage for concrete spalling or cracking. This may occur at the ends of the stems where drainage has seeped through the slab joints (see Figure 7.2.19).

Figure 7.2.19 Deteriorated Tee Beam End Due to Drainage

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars as well as the amount of concrete and steel section loss. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss of the reinforcement bars (see Figure 7.2.20).

Figure 7.2.20 Tee Beam Bridge Over a Highway

Examine areas that have been previously repaired. Determine if the repairs are in place, and if they are functioning properly.

7.2.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guidelines systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating. For concrete tee beams, the slab condition influences the superstructure component rating. When the slab component rating is 4 or less, the superstructure component rating may be reduced if the recorded slab defects reduce its ability to carry applied stresses associated with superstructure moments.

Application of Condition State Assessment (Element Level Inspection - Pontis)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of deck and the underside. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element Level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a tee beam bridge, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
12	Concrete Deck – Bare
13	Concrete Deck– Unprotected with AC Overlay
14	Concrete Deck – Protected with AC Overlay
18	Concrete Deck – Protected with Thin Overlay
22	Concrete Deck – Protected with Rigid Overlay
26	Concrete Deck – Protected with Coated Bars
27	Concrete Deck – Protected with Cathodic System
110	Concrete Open Girder/Beam

The unit quantity for the deck elements is "each", and for the tee beam it is linear meters or feet. The entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2). The inspector must know the total deck surface area in order to calculate a percent deterioration and fit into a given condition state description. The unit quantity for the girder is meters or feet, and the total length of all girders must be placed in one of the four available condition states. Condition state 1 is the best possible rating for the tee beam. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For structural cracks in the surface of bare decks, the "Deck Cracking" Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a deck element, the "Soffit" Smart Flag, Element No. 359, can be used and one of five condition states assigned. For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

This page intentionally left blank

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Topic 7.3 Concrete Girders

7.3.1 Introduction

Concrete girder bridges generally consist of cast-in-place monolithic decks and girder systems. Concrete girders can be used as deck girders, where the deck is cast on top of the girders (Figure 7.3.1), or as through girders, where the deck is cast between the girders. Through girders are very large in appearance and actually serve as the bridge's parapets, as well as the main supporting members (see Figure 7.3.2). Many of these bridges in service today were built in the 1940's.

Figure 7.3.1 Concrete Deck Girder Bridge

Figure 7.3.2 Concrete Through Girder Bridge

7.3.2 Design Characteristics

General

The deck slab does not contribute to the strength of the girders and serves only to distribute traffic loads to the girders. As such, the superstructure condition rating is not affected by the condition of the deck slab. If floorbeams are present, they are considered part of the superstructure.

Sometimes a concrete floorbeam and/or tee beam floor system is used between the deck girders (see Figure 7.3.3).

Figure 7.3.3 Concrete Deck Girder, Underside View

Concrete through girders are used for simple spans ranging from 9 to 18 m (30 to 60 feet) at locations with a limited under-clearance (see Figure 7.3.4). They are, however, not economical for wide roadways and are usually limited to about 7 m (24-foot) width. Girders are usually 450 to 760 mm (18 to 30 inches) wide and 1220 to 1830 mm (4 to 6 feet) deep.

Figure 7.3.4 Concrete Through Girder Elevation View

Care must be taken not to describe concrete girder bridges as composite. They do not meet the definition of composite because the concrete girders and deck consist of the same material, even though they are rigidly connected with rebars.

In a deck girder as well as a through girder structure, the live loads from the roadway surface are carried to the girders through the deck. The girders in turn carry the loads to the substructure.

Primary Members and Secondary Members

The primary members of a girder bridge are the girders, floorbeams (if present) and the deck. The secondary members consist of diaphragms or struts.

Steel Reinforcement

The primary (tension) reinforcing steel consists of main longitudinal reinforcement and shear reinforcement or stirrups. The main tension reinforcement is located in the bottom of the girder (positve moment) and on the top (negative moment). The beam also contains shear reinforcement, called stirrups, and are located throughout the girder length. Stirrups are generally U-shaped bars and run transversely across the bottom of the girder (see Figure 7.3.5). The need for stirrups is greatest near the beam supports where shear stresses are the highest.

The secondary (temperature and shrinkage) reinforcing steel is oriented longitudinally in the sides of the girders (see Figure 7.3.5). The primary and secondary reinforcing steel for the deck portion of the beam is the same as for a standard concrete deck.

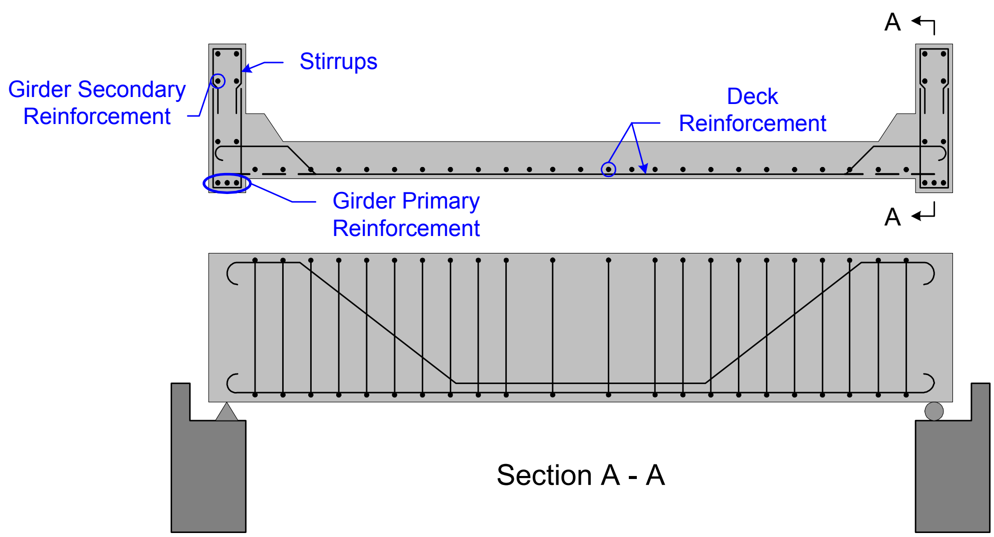


Figure 7.3.5 Steel Reinforcement in a Concrete Through Girder

7.3.3 Overview of Common Defects

Common defects that occur on concrete girder bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear

- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.3.4 Inspection Procedures and Locations

Inspecting a concrete girder bridge is similar to the procedure discussed in Topic 5.2.6, and includes the following specific procedures:

Procedures

Visual

The inspection of concrete girders for cracks, spalls, and other defects is primarily a visual activity. However, hammers can be used to detect areas of delamination. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

If the inspector deems it necessary, core samples can be taken from the girders and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete bridge girders are caused by corrosion of the rebar. When the deterioration of a concrete girder progresses to the point of needing rehabilitation, an in-depth inspection of the girder is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods

- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

Examine bearing areas for spalling where friction from thermal movement and high bearing pressure could cause the concrete to spall. Check for crushing of the girder near the bearing seat. Check the condition and operation of any bearing devices (see Figure 7.3.6).

Figure 7.3.6 Bearing Area of a Through Girder Bridge

Shear Zones

Investigate the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the girders or diagonal cracks on the sides of the girders indicate the onset of shear failure. These cracks indicate extreme shear stresses and should be carefully measured.

Tension Zones

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the bottom of the deck. The tension zones are at the midspan of the through girders along the bottom of the girder and possibly the deck for both simple and continuous span bridges (see Figure 7.3.7). Additional tension zones are located on the girders over the piers for continuous spans. Cracks greater that 2 mm (1/16 inch) wide are considered wide cracks and indicate extreme bending stresses.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete.

Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel and any lap splices may become exposed due to spalling (see Figure 7.3.8). Document the remaining crosssection of reinforcing steel since section loss will decrease live load capacity.

Figure 7.3.7 Typical Elevation View of a Through Girder Bridge

Figure 7.3.8 Exposed Reinforcement in a Through Girder (under hammer)

Areas Exposed to Drainage

Inspect areas exposed to drainage. These areas will usually be at any joints or around the scuppers. Look for contamination due to deicing agents on the interior face of through girders (see Figure 7.3.9). Check around drain holes for deterioration of girder concrete.

Figure 7.3.9 Close-up of a Girder with Heavy Scaling due to Deicing Agents

Areas Exposed to Traffic

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars as well as the amount of concrete and steel section loss. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss of the reinforcement bars.

Areas Previously Repaired

Examine areas that have been previously repaired. Determine if the repairs are in place and if they are functioning properly.

7.3.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the girder. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element Level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a concrete girder bridge, the AASHTO CoRe element is:

Element No.	Description
110	Concrete Open Girder/beam

The unit quantity for the girder/beam is meters or feet, and the total length of all girders must be placed in one of the four available condition states. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

This page intentionally left blank

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Topic 7.4 Concrete Channel Beams

7.4.1 Introduction

In appearance, the channel beam bridge resembles the tee beam bridge because the stems of the adjacent channel beams extend down to form a single stem (see Figure 7.4.1). In addition to the appearance of the finished concrete, the channel beam is different than the tee beam by the presence of a full-length seam or joint along the bottom of the stem (see Figure 7.4.2).

Figure 7.4.1 Underside View of Precast Channel Beam Bridge

Figure 7.4.2 General Underside View of Channel Beam Bridge

7.4.2 Design Characteristics

General

Channel beams are generally precast and consist of a mildly reinforced slab cast monolithically with two stems about 900 to 1200 mm (3 to 4 feet) apart (see Figure 7.4.3). Channel beams can also be cast-in-place with a curved underbeam soffit constructed over U-shaped beam forms (see Figure 7.4.4).

Precast channel beams may be conventionally reinforced or may be prestressed.

Figure 7.4.3 General View of a Precast Channel Beam Bridge

Figure 7.4.4 Underside View of a Cast-in-Place Channel Beam Bridge

Primary and Secondary Members

The primary members of channel beam bridges are the channel beams. Channel beams are usually found on spans up to 15 m (50 ft). As already mentioned, channel beams are usually precast, but they are sometimes cast-in-place on removable pan forms. The secondary members of channel beam bridges are the diaphragms.

Steel Reinforcement

Reinforcement cover for older channel beam bridges is often less than today's cover requirements. Air entrained concrete was not specified in channel beams fabricated in the 1940's and early 1950's, and concrete was often poorly consolidated.

The primary reinforcing steel consists of stem tension reinforcement and shear reinforcement or stirrups. The tension reinforcement is located in the bottom of the channel stem and oriented longitudinally. The tension steel reinforcement in current channel beams consists of either mild reinforcing bars or prestressing strands. The sides of the stems are reinforced with stirrups. The stirrups are located vertically in the sides of the channel stems at various spacings throughout the length and closer near the beam supports. The need for stirrups is greatest near the beam supports where the shear stresses are the highest.

The primary reinforcing steel for the slab portion of the beam is located in the bottom of the slab and is placed transversely, or perpendicular to the channel stems (see Figure 7.4.5).

The secondary (temperature and shrinkage) reinforcing steel is oriented longitudinally in the sides of deep channel stems and longitudinally in the slab. The primary and secondary reinforcing steel for the slab portion of the beam is the same as for a standard concrete slab (see Figure 7.4.5).

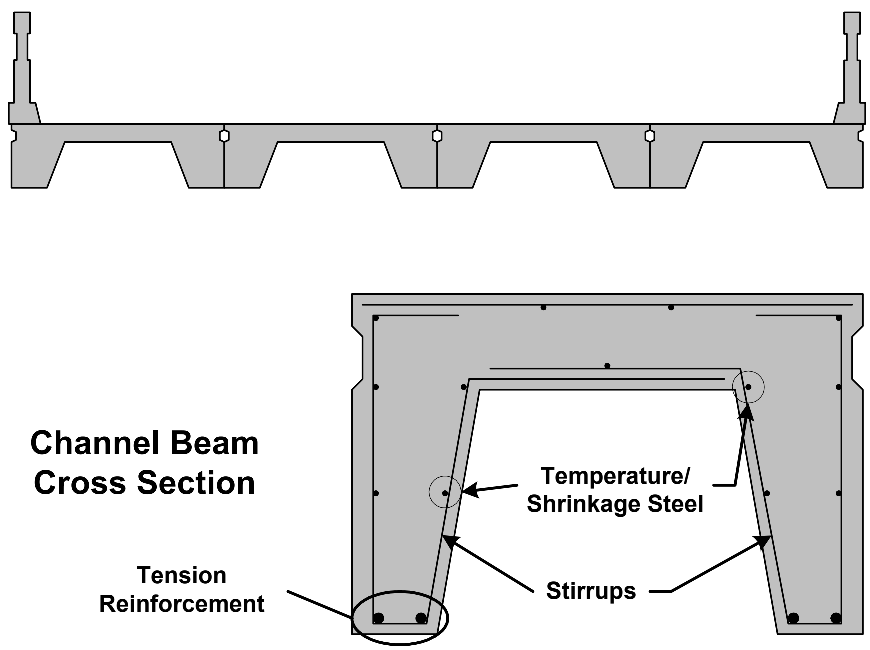


Figure 7.4.5 Cross section of a Typical Channel Beam

7.4.3 Overview of Common Defects

Common defects that occur on concrete channel beam bridges include:

- Cracking
- Scaling
- Delamination
- Spalling

- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.4.4 Inspection Procedures and Locations

Inspecting a channel beam bridge is similar to the procedure discussed in Topic 5.2.6, and includes the following specific procedures:

Procedures

Visual

The inspection of concrete slabs and stems for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination with a hammer can be a tedious operation. In most cases, a chain drag is used. A chain drag is made of several sections of chain attached to a pipe that has a handle attached to it. The inspector drags this across a slab and makes note of the resonating sounds. A chain drag can usually cover about a 900 mm (3-feet) wide section of slab at a time (see Figure 5.2.8).

If the inspector deems it necessary, core samples can be taken from the slab and stems and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete bridges are caused by corrosion of the rebar. When the deterioration of a concrete channel beam progresses to the point of needing rehabilitation, an in-depth inspection of the channel beam is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods

- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

Examine bearing areas for spalling where friction from thermal movement and high bearing pressure could cause the concrete to spall. Check for crushing of the stem near the bearing seat. Check the condition and operation of any bearing devices.

Shear Zones

Investigate the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the stem or diagonal cracks on the sides of the stems indicate the onset of shear failure. These cracks indicate extreme shear stresses and should be carefully measured.

High Moment Regions

Tension zones should be examined for flexure cracks, which would be vertical on the sides and transverse across the bottom of the stem. The tension zones are at the midspan along the bottom of the stem for both simple and continuous span bridges. Additional tension zones are located on the slab over the piers for continuous spans. Flexure cracks in the slab will be found on the underside in a longitudinal direction.

Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete. These could occur on both the concrete stems and the slab.

Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity. Check for evidence of sagging or camber loss (see Figure 7.4.6).

Figure 7.4.6 Excessive Deflection at Midspan

Areas Exposed to Drainage or Traffic

Inspect the seam or joint between two adjacent beams for leakage. Leakage generally indicates a broken shear key between the channel beams (see Figure 7.4.7). If signs of leakage are present between beams, the superstructure should be observed closely for differential beam deflection under live load (see Figure 7.4.8). Also, check beam ends for concrete deterioration due to leaking joints.

Examine areas exposed to drainage. Look for spalls and contamination at the ends and edges of the channel beams, scuppers, drain holes, and the curb line.

Check the tie-bolts for tightness and corrosion (see Figures 7.4.9 and 7.4.10).

Check the diaphragms for cracks which may occur from twisting or excessive deflection of the beams (see Figure 7.4.11).

Figure 7.4.7 Joint Leakage Between Channel Beams

Figure 7.4.8 Top of Slab View of Precast Channel Beam Bridge

Figure 7.4.9 Stem Tie-bolts

Figure 7.4.10 Close-up of Stem Tie-bolt

Figure 7.4.11 Close-up of Diaphragm

Check areas damaged by collision. Document the number of exposed and severed reinforcing bars, as well as the amount of concrete and steel section loss. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss of the reinforcement bars.

Damaged Areas

Examine areas that have been previously repaired. Determine if the repairs are in place, and if they are functioning properly.

7.4.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the element level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the beam. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a concrete channel beam bridge, the AASHTO CoRe element is:

Element No.	**Description**
110	Concrete Open Girder/beam
109	Prestressed Concrete Open Girder/beam

The unit quantity for the girder/beam is meters or feet, and the total length of all girders must be placed in one of the four available condition states. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

This page intentionally left blank

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

Topic 7.5 Concrete Arches and Arch Culverts

7.5.1 Introduction

A true arch has an elliptical shape and functions in a state of pure axial compression. It can be thought of as a long curved column. This makes the true arch an ideal form for the use of concrete. Unfortunately, the true arch form is often compromised to adjust for a specific bridge site. Because of this compromise, modern concrete arch bridges resist a load combination of axial compression, bending moment, and shear.

7.5.2 Design Characteristics

The basic design concept in arch construction utilizes a "building block" approach. Arch elements, although connected, are stacked or "bearing" on top of one another. The elements at the bottom of the pile receive the largest compressive loads due to the weight of the elements above. Arch spans are always considered "simple span" designs because of the basic arch function.

General

Open Spandrel Arch

The open spandrel concrete arch is considered a deck arch since the roadway is above the arches. The area between the arches and the roadway is called the spandrel.

Open spandrel concrete arches receive traffic loads through spandrel bents that support a slab or tee beam floor system (see Figure 7.5.1). This type of arch is generally for 61 m (200 feet) and longer spans.

Figure 7.5.1 Open Spandrel Arch Bridge

Closed Spandrel Arch

Closed spandrel arches are deck arches. The spandrel area (i.e., the area between the arch and the roadway) is occupied by fill retained by vertical walls. The arch member is called a ring or barrel and is continuous between spandrel walls.

Closed spandrel arches receive traffic loads through the fill material which is contained by spandrel walls (see Figure 7.5.2). This type of arch is efficient in short span applications.

Figure 7.5.2 Multi-span Closed Spandrel Arch Bridge

A closed spandrel arch with no fill material has a hollow vault between the spandrel walls. This type of arch has a floor system similar to the open spandrel arch and should be inspected accordingly.

Through Arch

A concrete through arch is constructed having the crown of the arch above the deck and the arch foundations below the deck. Hangers or cables suspend the deck from the arch. Concrete through arches are very rare (see Figure 7.5.3). These types of arches are sometimes referred to as “Rainbow Arches”.

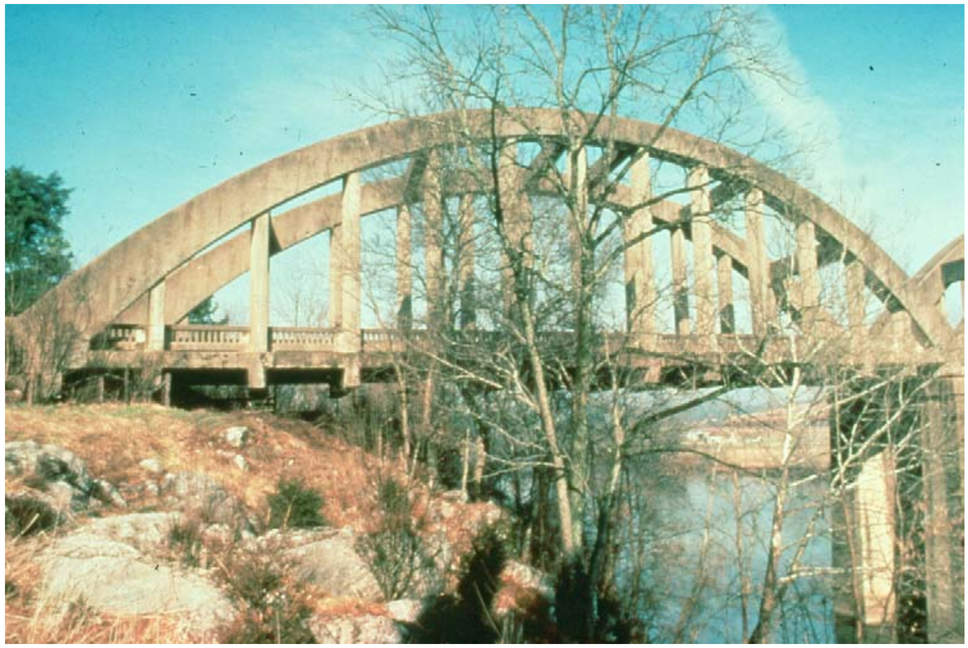


Figure 7.5.3 Concrete Through Arch Bridge

Precast Arch

Precast concrete arches are gaining popularity and can be integral or segmental. The integral arches typically have an elliptical barrel with vertical integral sides (see Figure 7.5.4). Segmental arches are oval or elliptical and can have several hinges along the arch (see Figure 7.5.5). The hinges allow for rotation and eliminate the moment at the hinge location. Both integral and segmental precast arch sections are bolted or post-tensioned together perpendicular to the arch.

Figure 7.5.4 Precast Concrete Arch with Integral Vertical Legs

Figure 7.5.5 Precast Segmental Concrete Arch

Large segmental precast arches that are post-tensioned have the ability to span great distances. This type of arch is constructed from the arch foundations to the crown using segmental hollow sections. The segmental sections are post-tensioned together along the arch through post-tensioning ducts placed around the perimeter of the segmental section. This type of design can be strong enough so that spandrel columns are not needed to support the deck (see Figure 7.5.6). For this type of design, the deck and supporting members bear on the top or crown of the arch.

High quality control can be obtained for precast arches. Sections are precast in a casting yard which allows manufacturers to properly monitor the concrete placement and curing. Reinforcement clearances and placement is also better controlled in a casting yard. Precast sections are typically tested prior to gaining acceptance for use. This ensures that the product can withstand the required loads that are applied.

Figure 7.5.6 Precast Post-tensioned Concrete Arch without Spandrel Columns

Arch Culvert

Although concrete arch culverts look like and experience most of the same defects as concrete arch bridges, concrete arch culverts are separate from concrete arch bridges due to hydraulic, structural, maintenance, traffic safety, construction, durability, and inspection differences. . An arch culvert is a curved shaped culvert that works primarily in compression. A variation of the arch culvert is the tied arch culvert. It is basically the same as the arch culvert, but it has an integral floor serving as a tie between the ends of the arch. Concrete arch culverts can be cast-in-place or precast. Unlike arch bridges, arch culverts are designed to flow full peak flows. Also, the embankment material surrounding an arch culvert is more important than the embankment material around an arch bridge. These differences plus others require special attention to be given to culverts (see Figure 7.5.7).

Figure 7.5.7 Concrete Arch Culvert

Primary Members and Secondary Members

Open Spandrel Arch

The reinforced concrete open spandrel arch consists of one or more arch ribs. The arch members are the primary load-carrying elements of the superstructure. The arch and the following members supported by the arch are also considered superstructure elements:

- Spandrel bents - support floor system
- Spandrel bent cap - transverse beam member of the spandrel bent
- Spandrel columns - vertical members of the spandrel bent which support the spandrel bent cap
- Spandrel beams - fascia beams of the floor system
- Floor system - a slab or tee beam arrangement supported by the spandrel bent caps and the substructure elements

The secondary members of an open spandrel arch bridge are the arch struts, which are transverse beam elements connecting the arch ribs. Arch struts provide stability against lateral forces (see Figure 7.5.8).

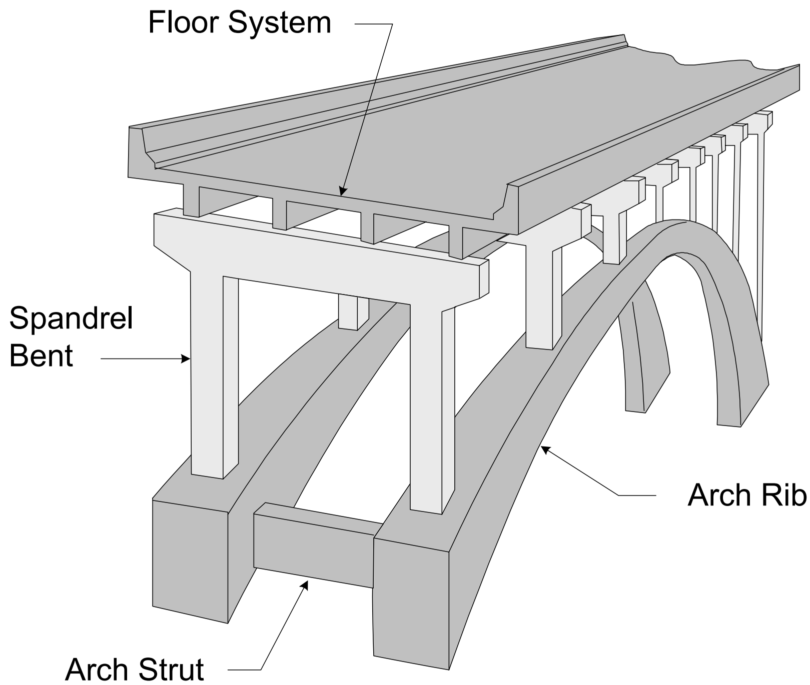


Figure 7.5.8 Primary and Secondary Members of an Open Spandrel Arch

Closed Spandrel Arch

For a closed spandrel arch, the primary members are the arch rings and spandrel walls. The arch rings support fill material, roadway, and traffic, while the spandrel walls retain fill material and support the bridge parapets.

The arch and members supported by the arch are superstructure elements. The arch itself is the primary load-carrying element of the superstructure (see Figure 7.5.9).

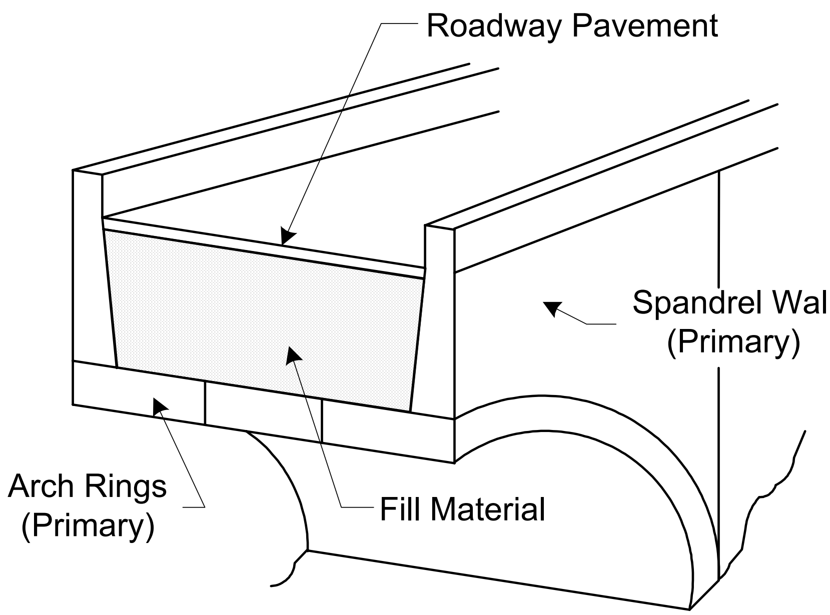


Figure 7.5.9 Primary Members of a Closed Spandrel Arch

Concrete Arch Culverts

The primary member in a concrete arch culvert is the culvert barrel. The barrel supports fill material and any live loads crossing the structure.

Steel Reinforcement

For the proper inspection and evaluation of concrete arch bridges and culverts, the inspector must be familiar with the location and purpose of steel reinforcement.

Open Spandrel Arch

The primary reinforcing steel in an open spandrel arch follows the shape of the arch from support to support. Since the arch is a compression member, reinforcement is similar to column reinforcement. The surfaces of the arch rib are reinforced with equal amounts of longitudinal steel held in place with lateral ties. This longitudinal or column reinforcement can act as compression reinforcement when the arch must resist moment due to axial load eccentricity or lateral loads. Spandrel columns are also compression members and are reinforced similar to the arch rib (see Figure 7.5.10).

In spandrel bent caps, the primary reinforcement is tension and shear steel. This is provided using "Z" shaped bars since the cap behaves like a fixed end beam (see Figure 7.5.11).

The floor system is designed and reinforced similar to other concrete beams (e.g. tee beams).

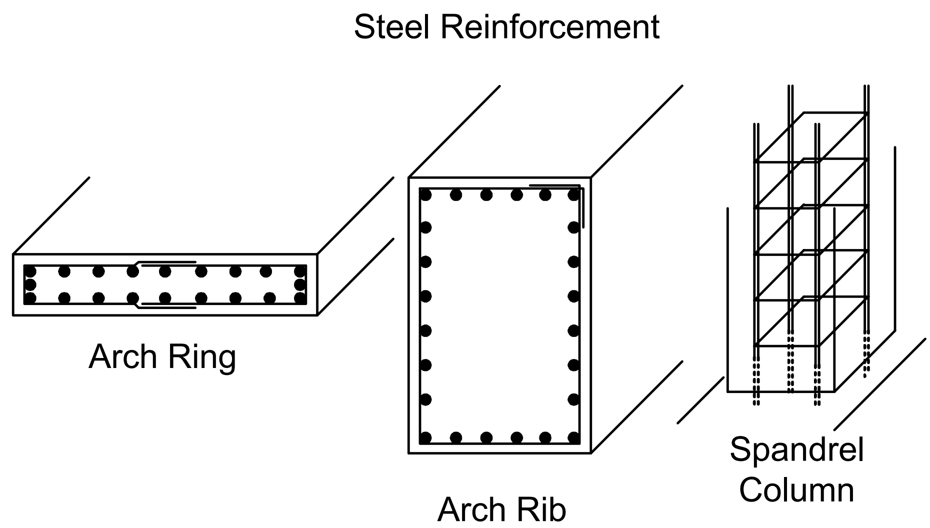


Figure 7.5.10 Open Spandrel Arch Reinforcement

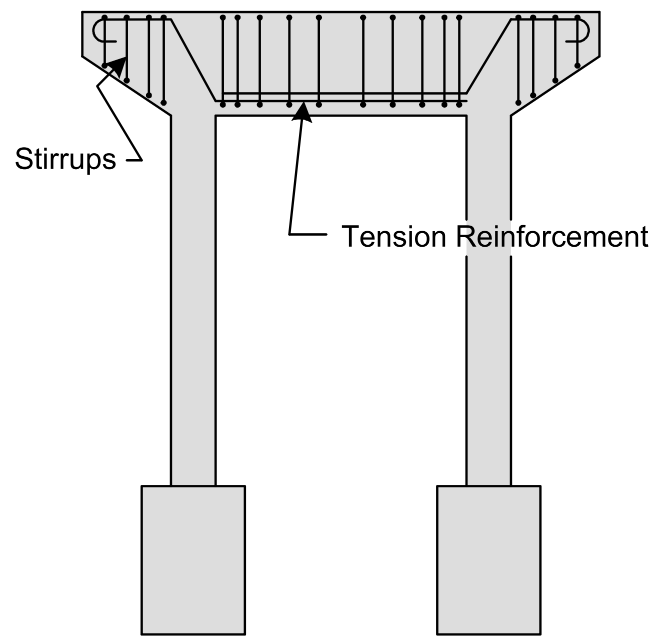


Figure 7.5.11 Spandrel Bent Cap Reinforcement

Closed Spandrel Arch

The primary reinforcing steel in the arch ring follows the shape of the arch from support to support and consists of a mat of reinforcing steel on both the top and bottom surfaces of the arch. The inspector will be unable to inspect the top surface of the arch due to the backfill.

The spandrel walls are designed to retain the backfill material. The primary tension steel for the wall is usually at the back, or unexposed, face of the wall, hidden from view. The front, or outside, face of the wall is reinforced in both directions with temperature and shrinkage steel (see Figure 7.5.12).

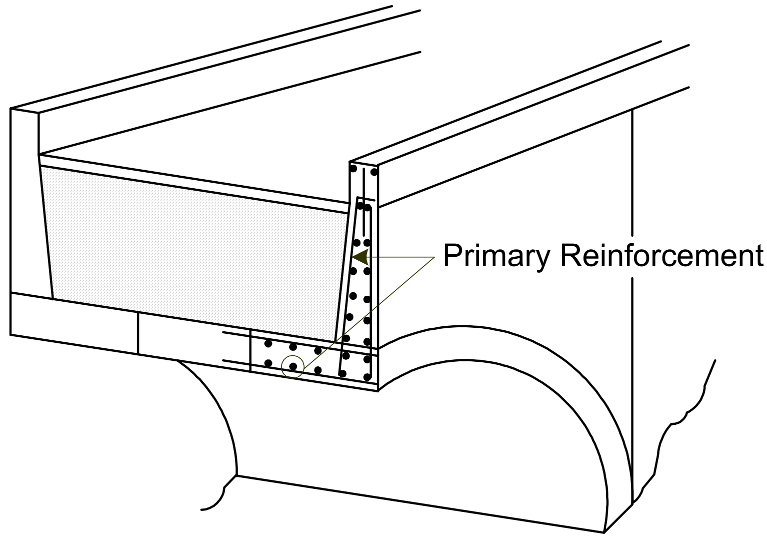


Figure 7.5.12 Reinforcement in a Closed Spandrel Arch

Arch Culvert

Reinforcement for arch culverts follows the shape of the arch from support to support. A mat of reinforcing steel is used on the top and bottom surfaces of the arch.

Other Reinforcement

Temperature and shrinkage reinforcement is used in the floor system for open spandrel arches.

A grid of temperature and shrinkage reinforcement is used in spandrel walls for closed spandrel arches.

7.5.3 Overview of Common Defects

Common defects that occur on concrete arches and culverts include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Collision damage
- Abrasion
- Overload damage
- Reinforcing/prestressing steel corrosion
- Stress corrosion

Refer to Topic 2.2 for a more detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.5.4 Inspection Procedures and Locations

Procedures

Visual

The inspection of concrete arches and culverts for cracks, spalls, and other defects is primarily a visual activity. However, hammers can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

If the inspector deems it necessary, core samples can be taken from the concrete and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete bridges are caused by corrosion of the rebar. When the deterioration of a concrete member progresses to the point of needing rehabilitation, an in-depth inspection of the member is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength

- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Open and Closed Spandrel Arches

Bearing Areas

- The arch/skewback interface has the greatest bearing load magnitude. Inspect for loss of cross section of the reinforcement bars at the spalls. Examine the arch for longitudinal cracks. These indicate an overstress condition.

- The arch/spandrel column interface has the second greatest bearing load magnitude. Examine for reinforcement cross-section loss at the spalls. Check for horizontal cracks in the columns within several meters from the arch. These indicate excessive bending in the column, which is caused by overloads and differential arch rib deflection.

- The spandrel column/cap interface has the third greatest bearing load magnitude. Inspect for loss of section due to spalling. Examine the column for diagonal cracks which begin at the inside corner and propagate upward. These indicate differential arch rib deflections (see Figure 7.5.13).

- The floor system/bent cap interface has the smallest bearing load magnitude. Examine bearing areas as described in the slab, tee beam and girder sections.

- Examine the arch ring for unsound concrete. Look for rust stains, cracks, discoloration, crushing, and deterioration of the concrete. The interface between the spandrel wall and the arch should be carefully inspected for spalls that could reduce the bearing area. Investigate the arch for transverse cracks, which indicate an overstress condition.

Figure 7.5.13 Spandrel Column Cap Interface

Shear Zones

- Check for shear cracks at the ends of the spandrel bent caps. When arch ribs are connected with struts, examine the arches near the connection for diagonal cracks due to torsional shear. These cracks indicate excessive differential deflection in the arch ribs. Also investigate the floor system for shear cracks.

Tension Zones

- Inspect the tension areas of the spandrel bent caps and columns (i.e., mid-span at the bottom and ends at the top) (see Figure 7.5.14). Also check the tension areas in the floor system.

- Check for transverse cracks in the arch which indicate an overstress condition. Transverse cracks are oriented perpendicular to the arch member.

- Inspect the spandrel walls for sound concrete. Look for cracks, movement, and general deterioration of the concrete (see Figure 7.5.15).

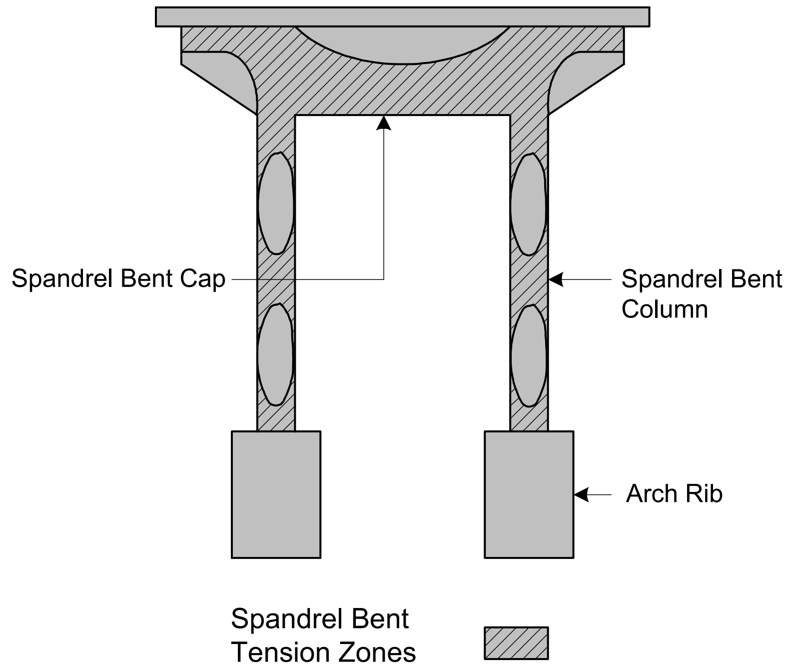


Figure 7.5.14 Spandrel Bent Tension Zone

Figure 7.5.15 Deteriorated Arch/Spandrel Wall Interface

Compression Zones

- Investigate the compression areas throughout the arches and spandrel columns (not only at the bearing areas). Transverse or lateral cracks indicate excessive surface stresses caused by buckling forces and bending moment (see Figure 7.5.16).

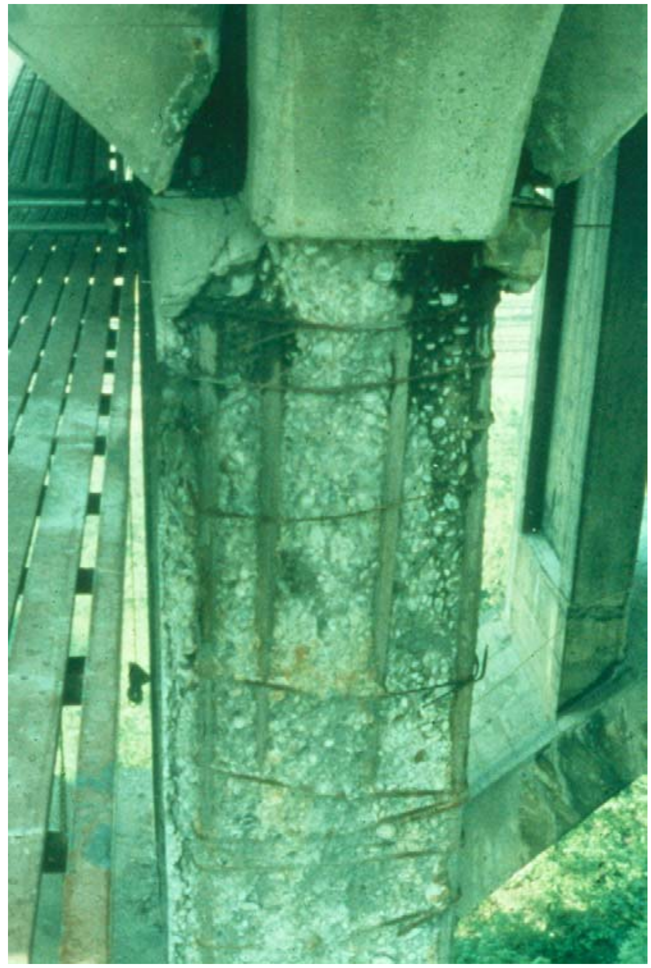


Figure 7.5.16 Severe Scaling and Spalling on a Spandrel Column

Areas Exposed to Drainage

- For an open spandrel arch, check the areas exposed to drainage and roadway runoff. Elements beneath the floor system are prone to scaling, spalling, and chloride contamination (see Figure 7.5.17).

- For a closed spandrel arch, make sure that weep holes are working properly.

- For a closed spandrel arch, check that surface water drains properly and does not penetrate the fill material.

Figure 7.5.17 Scaling and Contamination on an Arch Rib Due to a Failed Drainage System

Areas Exposed to Traffic

- Check areas damaged by collision. Document the number of exposed and severed reinforcing bars as well as the amount of concrete and steel section loss. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss of the reinforcing bars.

Previous Repairs

- Examine thoroughly any repairs that have been previously made. Determine if repaired areas are functioning properly. Effective repairs and patching are usually limited to protection of exposed reinforcement.

Concrete Arch Culverts

For a concrete arch culvert, the following locations should be inspected:

- Inspect the culvert barrel for rust stains, cracks, discoloration, crushing, and other deterioration of the concrete.

- Inspect the culvert barrel for spalls, delaminations, and rebar section loss.

- Check weep holes for partial or full blockage.
- Check approach conditions for dips, sags, cracks, pavement patches or other settlement indicators.
- Examine headwalls and wingwalls for undermining and settlement. Cracking, tipping, or separation of the barrel from the headwall are indications of undermining and settlement. Erosion is also a concern with headwalls and wingwalls.
- When dealing with precast concrete culverts, inspect for joint defects, leaking joints, cracked joints, and separated joints.
- Refer to Topics 11.1 through 11.3 for waterway inspection procedures and locations.

7.5.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible. The previous inspection data should be used along with current inspection findings to determine the correct rating (see Topic 4.2).

For concrete arch culverts, the NBIS rating guidelines yield a 1-digit code on the Federal (SI&A) sheet that indicates the overall condition of the culvert. The culvert item not only evaluates the structural condition of the culvert, but also encompasses the alignment, settlement in the approach roadway and embankment, joints, scour, and headwalls and wingwalls. Integral wingwalls are included in the evaluation up to the first construction or expansion joint. Like concrete arches, the 1-digit code that best describes the culvert's overall condition is chosen, and the rating codes range from 9 to 0, where 9 is the highest possible rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the concrete arch or concrete arch culvert. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element Level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a concrete arch or arch culvert, the AASHTO CoRe element is one or more of the following:

Element No.	**Description**
	Open Spandrel Arch
109	Open Girder/Beam (P/S Concrete)
110	Open Girder/Beam (Reinforced Concrete)
154	Floorbeam (P/S Concrete)
155	Floorbeam (Reinforced Concrete)
115	Stringer (stringer floorbeam system) (P/S Concrete)
116	Stringer (stringer floorbeam system) (Reinforced Concrete)
143	Arch (P/S Concrete)
144	Arch (Reinforced Concrete)
204	Column or Pile Extension (P/S Concrete)
205	Column or Pile Extension (Reinforced Concrete)
233	Cap (P/S Concrete)
234	Cap (Reinforced Concrete)
	Closed Spandrel Arch
143	Arch (P/S Concrete)
144	Arch (Reinforced Concrete)
	Arch Culvert
241	Arch Culvert (Precast, Prestressed, or Reinforced Concrete)

The quantities, when dealing with concrete arches or culverts, are all in meters or feet except for Elements 204 and 205, which are given in units of each. The above elements for concrete arches and culverts consist of three to five condition state descriptions to choose from for each element. All elements must be placed in one of the available condition states assigned for each element. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

Smart Flag element numbers available for use in the case of open and closed spandrel arches are 360 – settlement, 361 – scour, and 362 – traffic impact. Concrete arch culverts can use Smart Flag element numbers 361 or 362 if needed. One of three condition state descriptions is chosen for each Smart Flag element that is used.

Table of Contents

Section 7

Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Topic 7.6 Concrete Rigid Frames

7.6.1 Introduction

A concrete rigid frame structure is a bridge type in which the superstructure and substructure components are constructed as a single unit. Rigid frame action is characterized by the ability to transfer moments at the knee, the intersection between the frame legs and the frame beams or slab. Reinforced concrete rigid frame bridges and culverts are cast-in-place monolithic units.

7.6.2 Design Characteristics

General

The rigid frame bridge can either be single span or multi-span. Single span frame bridges span up to 15 m (50 feet) and are generally a slab beam design (see Figure 7.6.1). The basic single span frame shape is most easily described as an inverted "U".

Figure 7.6.1 Three Span Concrete Rigid Frame Bridge

Multi-span frame bridges are used for spans over 15 m (50 feet) with slab or rectangular beam designs (see Figure 7.6.2). Other common multi-span frame shapes include the basic rectangle, the slant leg or K-frame, and Delta frames (see Figure 7.6.3).

Figure 7.6.2 Typical Multi-span Rectangular Concrete Rigid Frame Bridge

Figure 7.6.3 Typical Concrete K-frame Bridge

Rigid frame structures are utilized both at grade and under fill, such as in concrete frame culverts (see Figure 7.6.4).

Figure 7.6.4 Typical Concrete Frame Culvert

Primary Members

For single span frames, the primary member is considered to be the slab portion above the "legs" of the frame (see Figure 7.6.5).

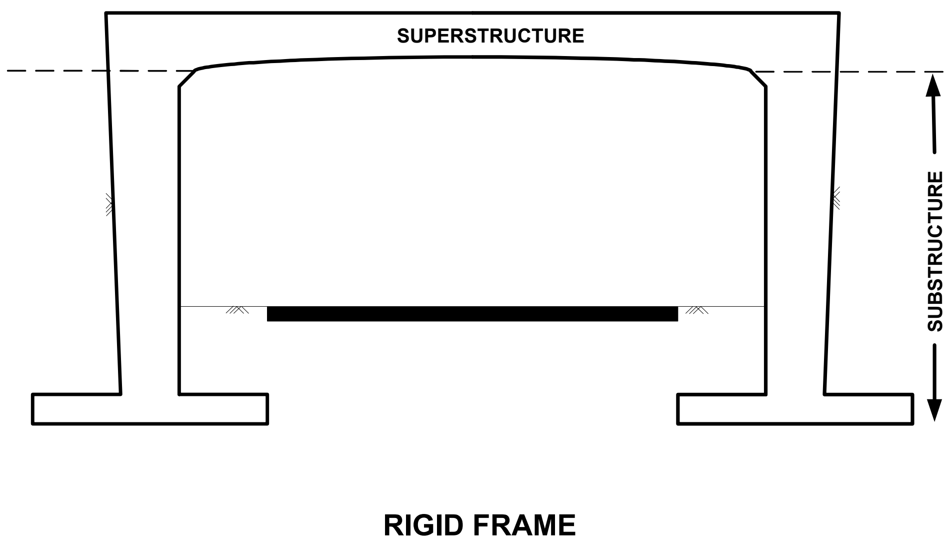


Figure 7.6.5 Elevation of a Single Span Slab Beam Frame

For multi-span frames, the primary members include the frame legs (the slanted beam portions which replace the piers) and the frame beams (the horizontal portion which is supported by the frame legs and abutments) (see Figure 7.6.6).

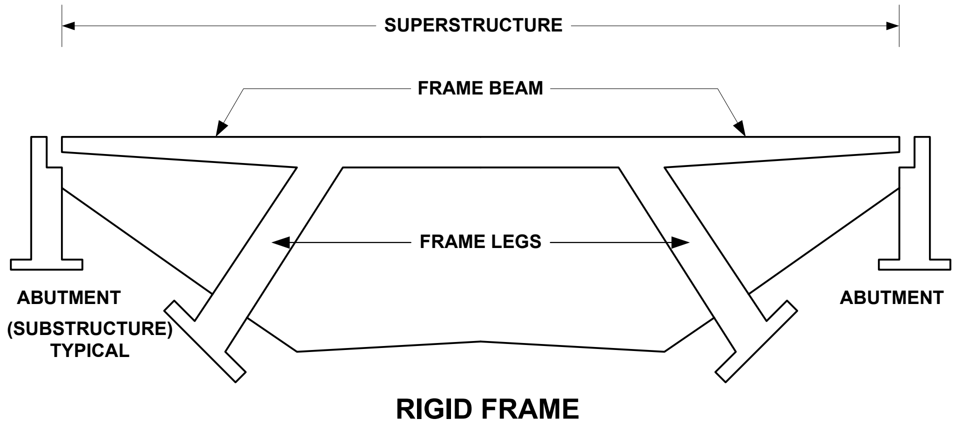


Figure 7.6.6 Elevation of a K-frame

Steel Reinforcement

Rigid frame structures develop positive and negative moment throughout due to the interaction of the frame legs and frame beams (see Figure 7.6.7). In slab beam frames, the primary reinforcement is tension steel.

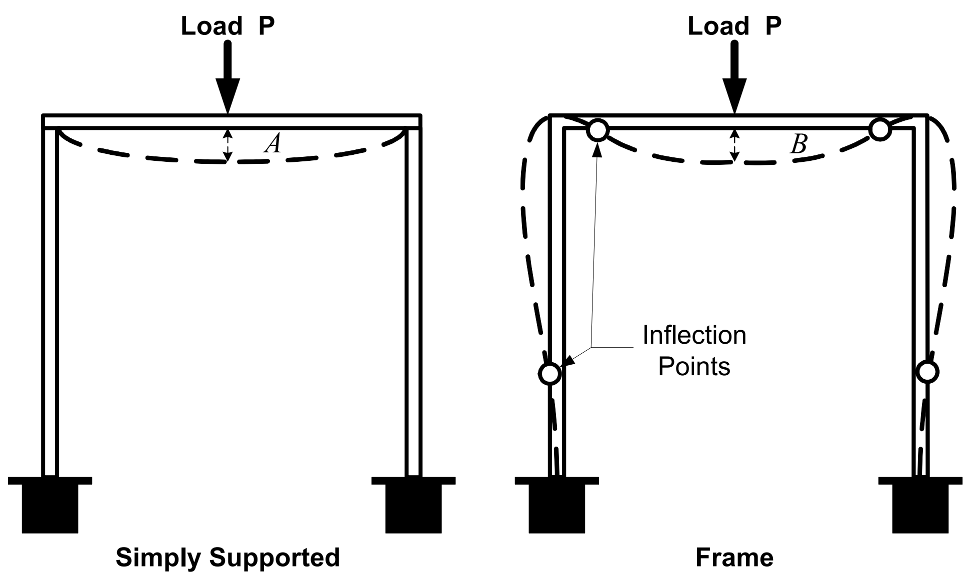
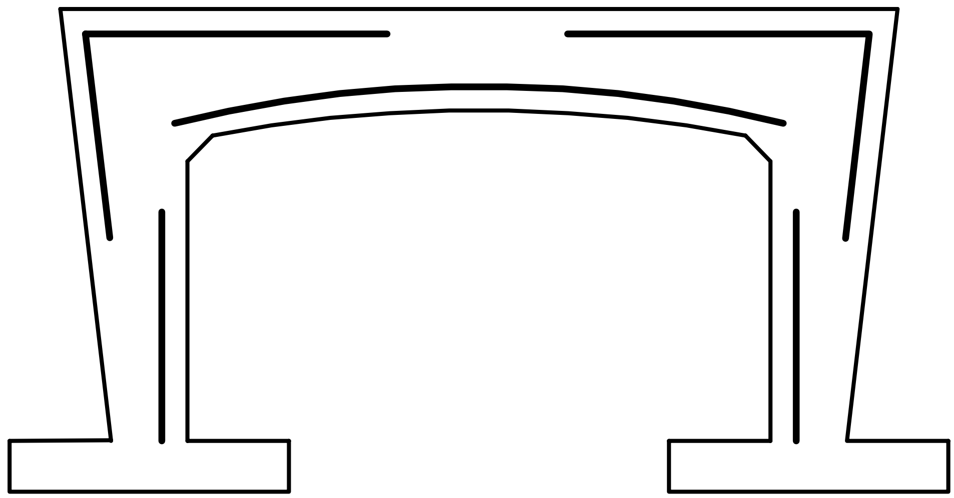


Figure 7.6.7 Deflected Frame Shape

Primary Reinforcement

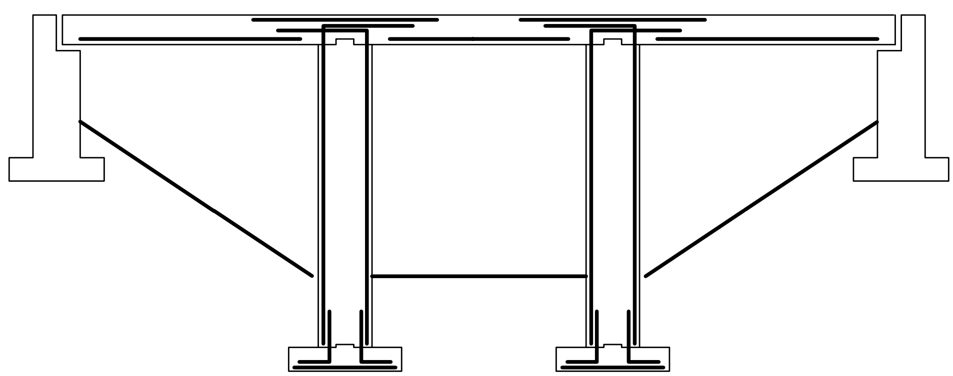
For gravity and traffic loads on single span slab frames, the tension steel is placed longitudinally in the bottom of the frame slab, vertically in the front face of the frame legs, and longitudinally and vertically in the outside corners of the frame (see Figure 7.6.8).



PRIMARY REINFORCEMENT

Figure 7.6.8 Tension Reinforcement in a Single Span Slab Beam Frame

For multi-span slab frames, the tension steel is placed longitudinally in the top and bottom of the frame slab and vertically in both faces of the frame legs (see Figure 7.6.9).



PRIMARY REINFORCEMENT

Figure 7.6.9 Tension Reinforcement in a Multi-span Beam Frame

In the beam portion of rectangular beam frames, the primary reinforcement is tension and shear steel, similar to continuous beam reinforcement. In the frame legs, the primary reinforcement is tension and shear steel near the top and compression steel with column ties for the remaining length (see Figure 7.6.10).

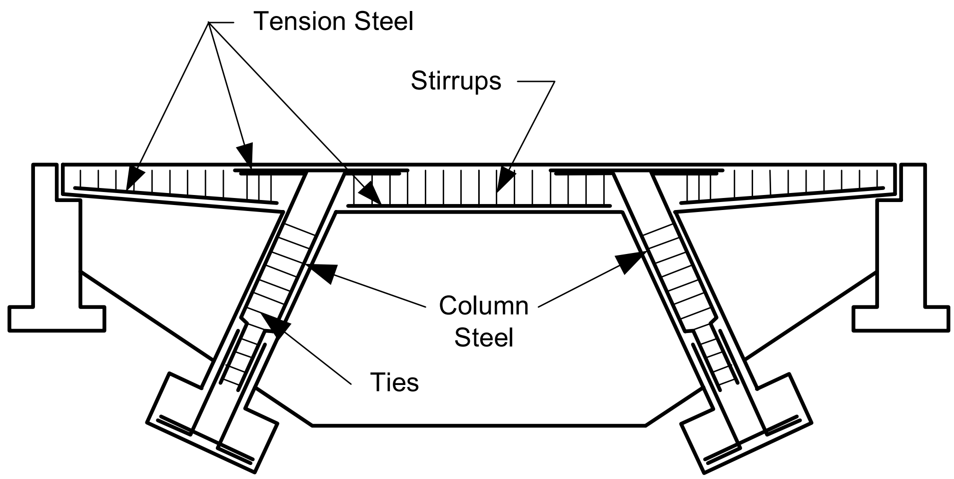


Figure 7.6.10 Tension, Shear, and Column Reinforcement in a Typical K-frame

Secondary Reinforcement

Temperature and shrinkage reinforcement is also included in both sides of the slab frames and in the beam portion of rectangular beam frames. Secondary reinforcement is perpendicular to the tension reinforcement.

7.6.3 Overview of Common Defects

Common defects that occur on concrete rigid frame bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.6.4 Inspection Procedures and Locations

Inspecting a rigid frame bridge is similar to the procedures discussed in Topic 5.2.6 and includes the following specific procedures:

Procedures

Visual

The inspection of concrete rigid frames for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of a concrete rigid frames with a hammer can be a tedious operation. In most cases, a chain drag is used. A chain drag is made of several sections of chain attached to a pipe that has a handle attached to it. The inspector drags this across a deck and makes note of the resonating sounds. A chain drag can usually cover about a 900 mm (3-feet) wide section of deck at a time (see Figure 5.2.8).

If the inspector deems it necessary, core samples can be taken from the rigid frame and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete rigid frames are caused by corrosion of the rebar. When the deterioration of a concrete rigid frame progresses to the point of needing rehabilitation, an in-depth inspection of the rigid frame is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

Examine the bearing areas for spalling. Check the condition of the bearings, if present.

Shear Zones

Inspect the joint zones where the frame legs meet the frame beams. Look for shear cracks in the frame beams (beginning at the frame legs and propagating toward the adjacent span), in the frame legs (beginning at the top and propagating downward), and in the ends of the frame beams at the end spans (see Figure 7.6.11).

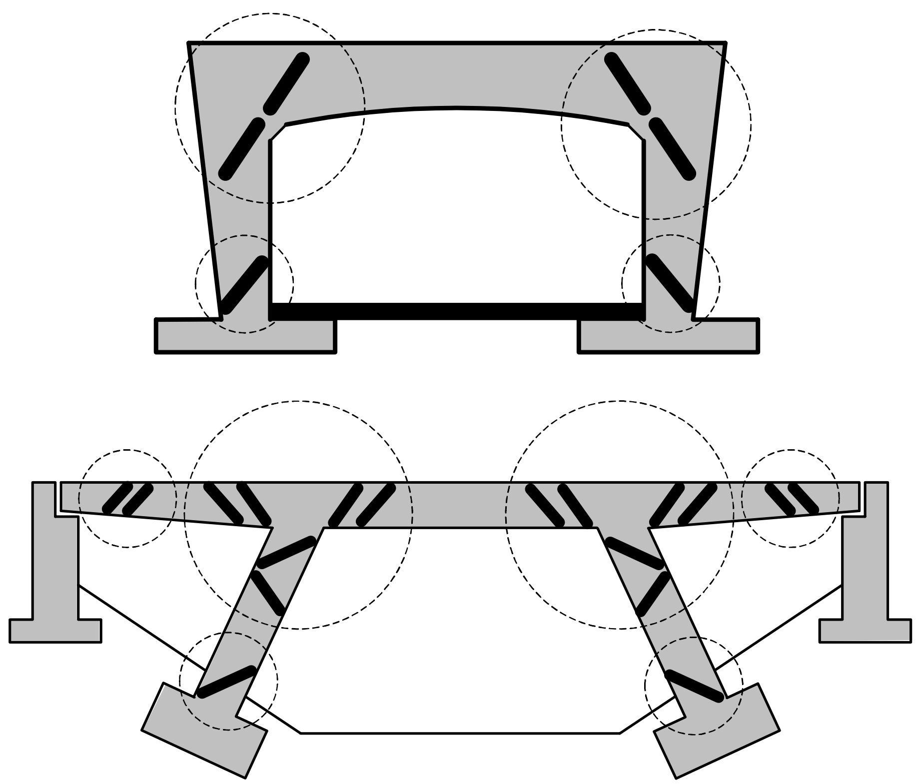


Figure 7.6.11 Shear Zones in Single Span and Multi-span Frames

Tension Zones

Investigate the tension areas for flexure cracks, rust stains, efflorescence, exposed and corroded reinforcement, and deteriorated concrete which would cause debonding of the tension reinforcement. The tension areas are located at the bottom of the frame beam at mid-span, the base of each frame leg (usually buried), and the inside faces of the frame legs at mid-height of single span slab frames (see Figures7.6.12 and 7.6.13).

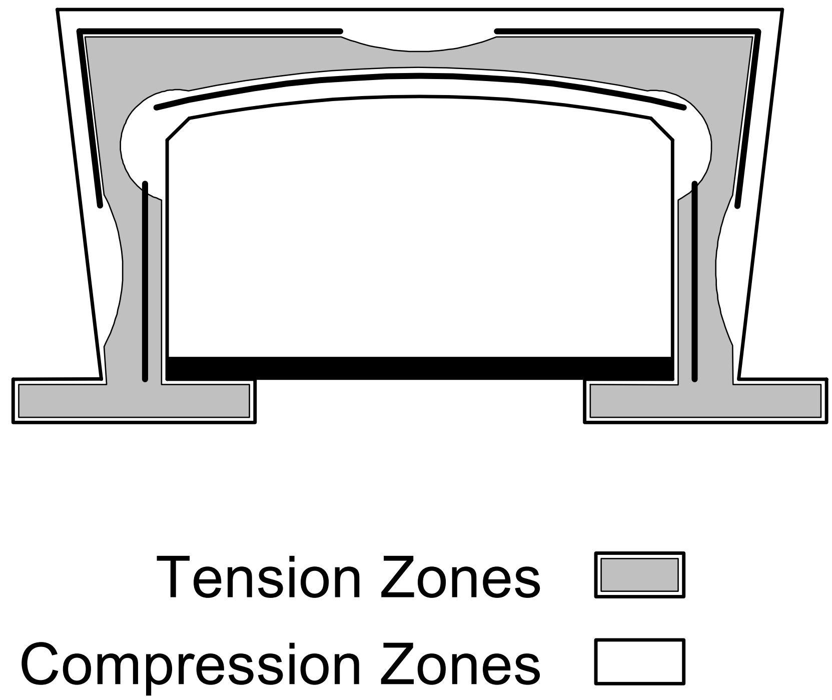


Figure 7.6.12 Tension Zones in a Single Span Beam Frame

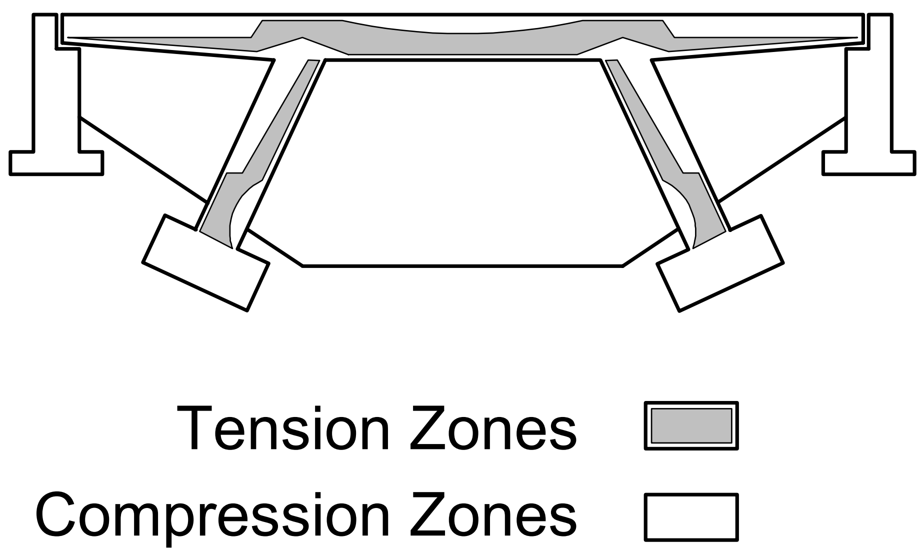


Figure 7.6.13 Tension Zones in a Multi-span Frame

Compression Zones

Investigate the compression areas for spalling, scaling, and exposed reinforcement. The legs of a frame act primarily as columns with a moment applied at the top (see Figure 7.6.14). Check the entire length of the frame legs for horizontal cracks, which indicate buckling.

Figure 7.6.14 K-frame Leg

Areas Exposed to Drainage

Examine the areas exposed to drainage for deteriorated and contaminated concrete. Check the roadway surface of the slab beam frames for delamination and spalls (see Figure 7.6.15). Special attention should be given to the tension zones and water tables.

Figure 7.6.15 Roadway of a Rigid Frame Bridge with Asphalt Wearing Surface

Check longitudinal joint areas of adjacent slab beam frames for leakage and concrete deterioration (see Figure 7.6.16). Check around scuppers and drain holes for deteriorated concrete. Check frame beam ends for deterioration due to leaking deck joints.

Figure 7.6.16 Longitudinal Joint Between Slab Beam Frames

Footings - When an invert slab is not used and the footings are exposed, they should be inspected for undermining and scour. A probing rod or bar should be used to check for voids and scoured areas that may have filled with sediment.

For additional inspection procedures and locations unique to culvert waterways, see Topic 7.12.

7.6.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the element level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the superstructure. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element level Smart Flags are also used to describe the condition of the concrete superstructure.

There is no specific element level condition state assessment of a concrete rigid frame bridges. The following AASHTO CoRe elements may be used to best describe a concrete rigid frame:

Element No.	**Description**
038	Concrete Slab - Bare
052	Concrete Slab – Protected with Coated Bars
053	Concrete Slab – Protected with Cathodic System
110	Concrete Open Girder/beam
205	Column or Pile Extension – Reinforced Concrete
210	Pier Wall – Reinforced Concrete
215	Abutment – Reinforced Concrete
241	Reinforced Concrete Culvert

The unit quantity for slab and columns is each. The unit quantity for the girder/beam and pier wall is meters or feet, and the total length of must be placed in one of the available condition states. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

Topic 7.7 Precast and Prestressed Slabs

7.7.1 Introduction

Precast and prestressed slabs have gained popularity since the 1950's (refer to Topic 2.2). This type of design acts as a deck and superstructure combined (see Figure 7.7.1). Individual members are placed side by side and connected together so they act as one. This type of design is effective, due to the slab's shallow depth, when vertical clearances are lacking. Wearing surfaces are generally applied to the top of precast and prestressed slabs and are either concrete or bituminous.

Figure 7.7.1 Typical Prestressed Slab Beam Bridge

Although precast and prestressed slabs are different from concrete decks, the design characteristics, wearing surfaces, protection systems, common defects, inspection procedures and locations, evaluation, and motorist safety concerns are similar to concrete decks. Refer to Topic 5.2 for additional information about concrete decks.

7.7.2 Design Characteristics

Fabrication Method

The precast voided slab bridge is the modern replacement of the cast-in-place slab. This type of bridge superstructure is similar to the cast-in-place slab in appearance only. It is comprised of individual precast slab beams fabricated with circular voids. The voids afford economy of material and reduce dead load (see Figure 7.7.2). Precast slab bridges with very short spans may not contain voids.

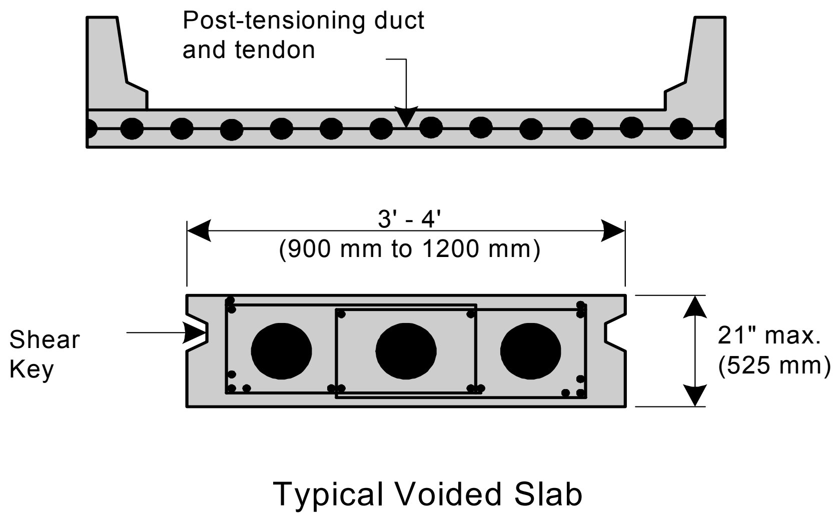


Figure 7.7.2 Cross Section of a Typical Voided Slab

Monolithic Behavior

Precast slab units are practical for spans of 6 to 15 m (20 to 50 feet). The slabs can be single or multiple simple spans. The units are typically 914 to 1219 mm (36 or 48 inches) wide and have a depth of 381, 457, or 533 mm (15, 18, or 21 inches). These special precast units are generally comprised of 28 to 56 MPa (4,000 up to 8,000 psi) prestressed concrete, and reinforced with 1860 MPa (270 ksi) pre- or post-tensioned steel tendons. Adjacent slab units are post-tensioned together with tie rods and grouted at the shear keys. This enables the slab units to act monolithically. Drain holes are placed strategically in the bottom of the slab to allow accumulated moisture to escape.

Identifying Voided Slabs

Physical dimensions alone are not enough to distinguish a slab unit from a box beam. Design or construction plans need to be reviewed. A box beam has one rectangular void, bounded by a top slab, bottom slab, and two webs. A voided slab section has two or three circular voids through it. It is also possible to find precast solid slab units.

Primary Members

The primary members of a precast voided slab bridge are the individual slab units. The slab units make up the superstructure and the deck and are commonly protected by an asphalt or concrete overlay.

Steel Reinforcement

Primary Reinforcement

The primary reinforcement consists of main tension steel and shear reinforcement or stirrups.

Prestressing strands placed near the bottom of the slab make up the main tension steel. Draped strands are often located in the webs. Depending on the age of the structure, the strand size will be 6, 10, 11, or 13 mm (1/4, 3/8, 7/16, or 1/2 inch) diameter. Strands are normally spaced 50 mm (2 inches) on center (see Figure 7.7.3). Shear reinforcement consists of U-shaped stirrups located throughout the slab at various spacings required by design.

Other Reinforcement

Other reinforcement is provided to control temperature and shrinkage cracking. This reinforcement is placed longitudinal in the beam.

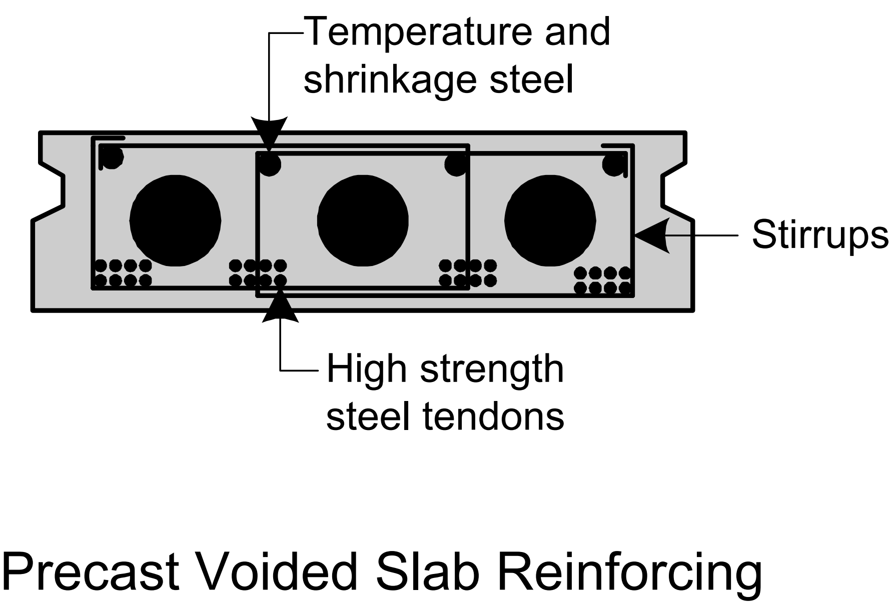


Figure 7.7.3 Prestressed Slab Beam Bridge Reinforcement

7.7.3 Overview of Common Defects

Common defects that occur on precast and prestressed slab bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Stress corrosion

Refer to Topic 2.2 for a more detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.7.4 Inspection Procedures and Locations

Inspect a precast voided slab bridge similar to as described in Topic 5.2.6 and using the following procedures.

Procedures

Visual

The inspection of concrete slabs for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of a slab with a hammer can be a tedious operation. In most cases a chain drag is used. A chain drag is made of several sections of chain attached to pipe that has a handle attached to it. The inspector drags this across a deck and makes note of the resonating sounds. A chain drag can usually cover about a 900-mm (3-feet) wide section of deck at a time (see Figure 5.2.8).

If the inspector deems it necessary, core samples can be taken from the slab and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete slabs are caused by corrosion of the rebar. When the deterioration of a concrete slab progresses to the point of needing rehabilitation, an in-depth inspection of the slab is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes

- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

- Examine the bearing areas for spalling concrete. End spalling can eventually lead to the loss of bond in the prestressing tendons. Bearing areas should also be checked for defects or deterioration due to leaking joints or poor quality control.

- Check bearing areas for spalls or vertical cracks. Spalls and cracks may be caused by corrosion of steel due to water leakage or restriction of thermal movement due to a faulty bearing mechanism.

Shear Zones

- Inspect near the supports for diagonal or shear cracks.

- Inspect between the slab sections for leakage and for reflective cracking in the traffic surface (see Figure 7.7.4). These problems indicate failed shear keys and that the slab units are no longer tied together. Observe if there is differential slab beam deflection under live load.

Figure 7.7.4 Leaking Joint between Adjacent Slab Units

Tension Zones

- Check the bottom of the slab sections for flexure cracks due to positive moments. Since prestressed concrete is under high compressive forces, no cracks should be visible. Cracks can be a serious problem since they indicate overloading or loss of prestress. Cracks that may be present will be difficult to detect with the naked eye. To improve detection, a common practice is to wet the slab surface with water using a spray bottle. Capillary action will draw water into a crack, thus producing a visible line when the surrounding surface water evaporates. All cracks should be measured with an optical crack gauge.

- Examine the top of the slab sections (if exposed) near the ends for tensile cracks due to prestress eccentricity. This indicates excessive prestress force. If the top of the slab has a wearing surface applied, check for cracks in the wearing surface. Cracks in the wearing surface may be an indication that the slab is overstressed or that water is getting to the slab.

- Investigate for evidence of sagging, which indicates a loss of prestress. Use a string line or site down the bottom edge of the fascia slab.

- Inspect the slabs for exposed strands. Prestressed strands will corrode rapidly and fail abruptly. Therefore, any exposure is significant (see Figure 7.7.5).

- Check for longitudinal cracking in skewed slab members (see Topic 7.10.4).

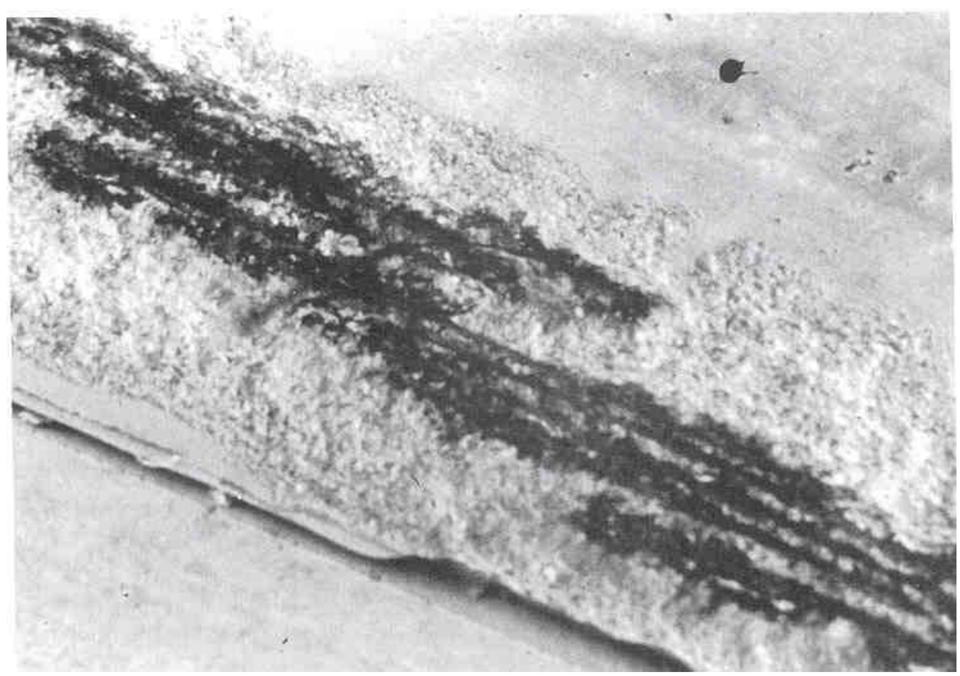


Figure 7.7.5 Exposed Strands in a Precast Slab Beam

Areas Exposed to Drainage

- Investigate areas exposed to drainage for deteriorated and contaminated concrete.

Areas over Traffic

- When precast voided slab superstructures are used for a grade crossing, check the areas over the traveling lanes for collision damage. This is generally not a problem due to the clearance afforded by the relatively shallow units.

Previous Repairs

- Examine thoroughly any repairs that have been previously made. Determine if repaired areas are sound and functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

General

- Check the camber of the slab units. Loss of positive camber indicates loss of prestress in the tendons.

- Check the condition of the lateral post-tensioning grout pockets. Cracked grout or rust stains may indicate a failure of the post-tensioning tendon.

7.7.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guidelines systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the element level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2). For a precast or prestressed slab bridge, these guidelines must be applied for both the deck component and the superstructure component.

The previous inspection data should be used along with current inspection findings to determine the correct rating. Typically, for this type of structure, the deck and superstructure components will have the same rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of slab and the underside. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a precast or prestressed slab bridge, the AASHTO CoRe element is one of the following depending on the riding surface:

Element No.	**Description**
38	Concrete Slab – Bare
39	Concrete Slab – Unprotected with AC Overlay
40	Concrete Slab – Protected with AC Overlay
44	Concrete Slab – Protected with Thin Overlay
48	Concrete Slab – Protected with Rigid Overlay
52	Concrete Slab – Protected with Coated Bars
53	Concrete Slab – Protected with Cathodic System
104	P/S Closed Web/Box Girder

The unit quantity for these elements is "each" for decks, and the entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2) for decks. The unit quantity for girders is "meter" or "linear foot", and the total length of all girders combined must be rated in one of the available condition states for girders. Element 104 is the closest choice in the National Highway Institute (NHI) element list for precast/prestressed slabs. States may decide to choose their own element number for precast/prestressed slabs because the NHI does not have a specific element number for prestressed slabs. Condition state 1 is the best possible element level rating. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit it into a given condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For structural cracks in the surface of bare slabs, the "Deck Cracking" Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a slab element, the "Soffit" Smart Flag, Element No. 359, can be used and one of five condition states assigned.

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Topic 7.8 Prestressed Double Tees

7.8.1 Introduction

A prestressed double tee beam, like the name implies, resembles two capital letter T's that are side by side (see Figure 7.8.1). The horizontal section is called the deck or flange, and the two vertical leg sections are called the webs or stems. This type of bridge beam is mostly used in short spans or in situations where short, obsolete bridges are to be replaced.

Figure 7.8.1 Typical Prestressed Double Tee Beam

7.8.2 Design Characteristics

General

Prestressed concrete double tee beams are a monolithic deck and stem design that allows the deck to act integrally with the superstructure. The integral design provides a stiffer member, while the material-saving shape reduces the dead load (see Figure 7.8.2).

This type of construction was originally used for buildings and is quite common in parking garages. They have been adapted for use in highway structures.

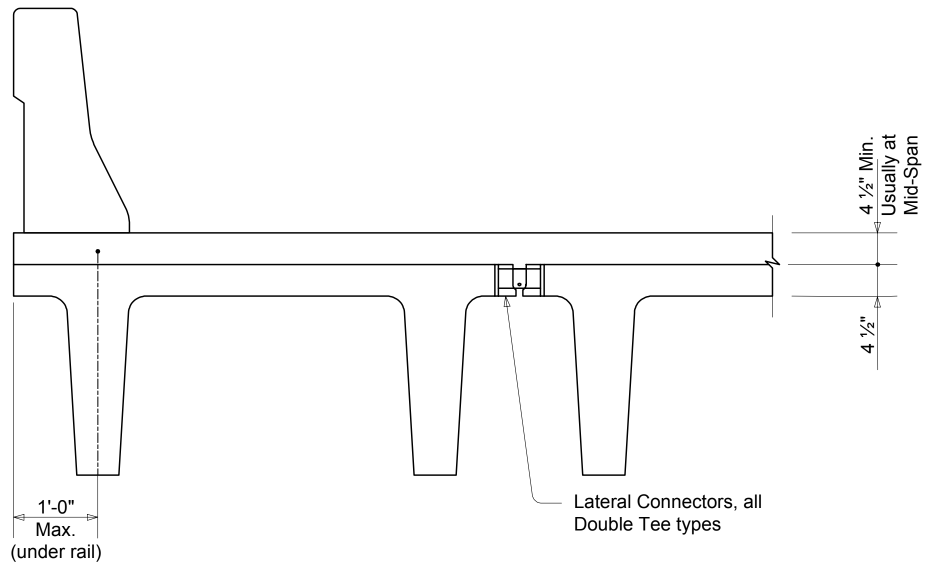


Figure 7.8.2 Prestressed Double Tee Beam Typical Section

Prestressed double tees have a typical stem depth of 305 to 864 mm (12 to 34 inches). The average flange width is 2.4 to 3.1 m (8 to 10 feet), with a typical span length of approximately 7.6 to 16.8 m (25 to 55 ft). Prestressed double tees can be used in spans approximately 24.4 m (80 ft) long with stem depths up to 1.5 m (5 feet) and flange widths up to 3.7 m (12 feet). Prestressed double tee bridges are typically simple spans, but continuous spans have also been constructed. Continuity is achieved from span to span by forming the open section between beam ends, placing the required reinforcement, and casting concrete in the void area. Once the concrete reaches its design strength, the spans are considered to be continuous for live load.
In some prestressed double tee designs, the depth of the stems at the beam end is dapped, or reduced (see Figure 7.8.3). This occurs so that the beam end can sit flush on the bearing seat.

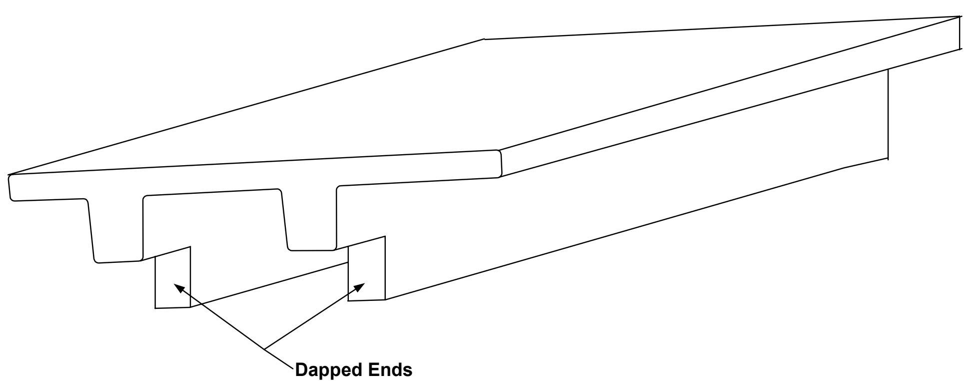


Figure 7.8.3 Dapped End of a Prestressed Double Tee Beam

The top of the flange or deck section of prestressed double tees can act as the wearing surface or be overlaid. Bituminous asphalt and concrete are typical examples of wearing surfaces that may be applied. See Topic 5.2.3 for a detailed description of the different types of concrete deck wearing surfaces.

Primary Members and Secondary Members

The primary members of a prestressed double tee beam are the stems and the deck.

The secondary members of a prestressed double tee bridge are the transverse diaphragms. The diaphragms are located at the span ends. They connect adjacent stems and prevent lateral movement. In the case of longer spans, intermediate diaphragms may also be placed to compensate for torsional forces. The diaphragms can be constructed of reinforced concrete or steel.

Steel Reinforcement

The primary tension steel reinforcement consists of prestressing strands and mild shear reinforcement (see Figure 7.8.4). The prestressing strands are placed longitudinally in each stem at the required spacing and clearance. When the double tees are to be continuous over two or more spans, conduits may be draped through the stems of each span to allow for post-tensioning. The shear reinforcement in a prestressed double tee beam consists of vertical U-shaped stirrups that extend from the stem into the flange. The shear reinforcement or stirrups are spaced along the length of the stem at a spacing required by design. The primary reinforcement for the deck or flange section of a prestressed double tee beam follows the reinforcement pattern of a typical concrete deck (see Topic 5.2.2). In some wider applications, the deck or flange portions of adjacent prestressed double tee beams may be transversely post-tensioned together through post-tensioning ducts. Transverse post-tensioning decreases the amount of damage that can occur to individual flange sides due to individual deflection and helps the double tee beams deflect as one structure.

The secondary or temperature and shrinkage reinforcement is placed longitudinally on each side of each stem and is tied to the vertical shear stirrups. In some newer designs, welded-wire-fabric is used as the shear and secondary reinforcement. The vertical bars in the welded-wire-fabric act as the shear reinforcement and the longitudinal bars perform as the secondary reinforcement. Tests have shown that temperature and shrinkage cracking can be reduced when welded-wire-fabric is used.

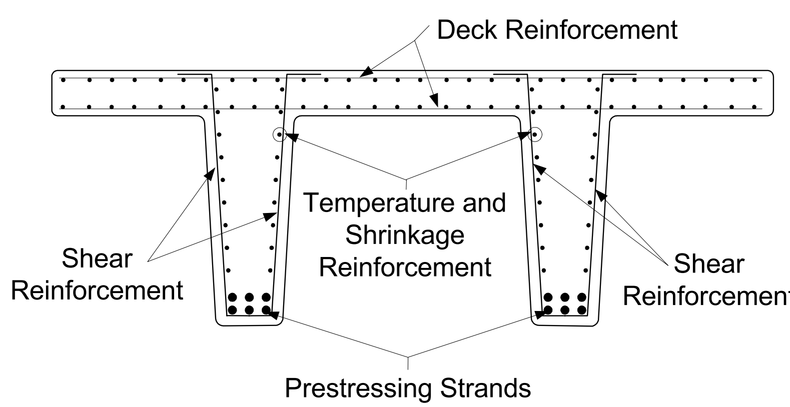


Figure 7.8.4 Steel Reinforcement in a Prestressed Double Tee Beam

7.8.3 Overview of Common Defects

Common defects that occur on prestressed concrete double tee beam bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Mild reinforcing steel corrosion
- Stress corrosion of prestressing strands

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.8.4 Inspection Procedures Locations

The inspection procedures and locations for concrete decks, as described in Topic 5.2.6, should be followed when inspecting the deck area of a prestressed double tee beam superstructure. For the stems, diaphragms, and other general locations, the bridge inspector should take into account the following:

Procedures

Visual

The inspection of concrete decks for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of a deck with a hammer can be a tedious operation. In most cases, a chain drag is used. A chain drag is made of several sections of chain attached to pipe that has a handle attached to it. The inspector drags this across a deck and makes note of the resonating sounds. A chain drag can usually cover about a 915-mm (3-feet) wide section of deck at a time (see Figure 5.2.8).

If the inspector deems it necessary, core samples can be taken from the deck and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete bridge decks are caused by corrosion of the rebar. When the deterioration of a concrete deck progresses to the point of needing rehabilitation, an in-depth inspection of the deck is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core Sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

- Examine bearing areas for spalling where friction from thermal movement and high bearing pressure could cause the concrete to spall. Check for crushing of the stem near the bearing seat. Check the condition and operation of any bearing devices.

- For dapped-end double tee beams, look for vertical flexure cracks and diagonal shear cracks in the reduced depth section that sits on the bearing seat. At the full depth-to-reduced depth vertical interface, check for vertical direct shear cracking. At the bottom corner where the reduced section meets the full depth section, check for diagonal shear corner cracks. At the bottom corner of the full depth section, check for diagonal tension cracks (see Figure 7.8.5).

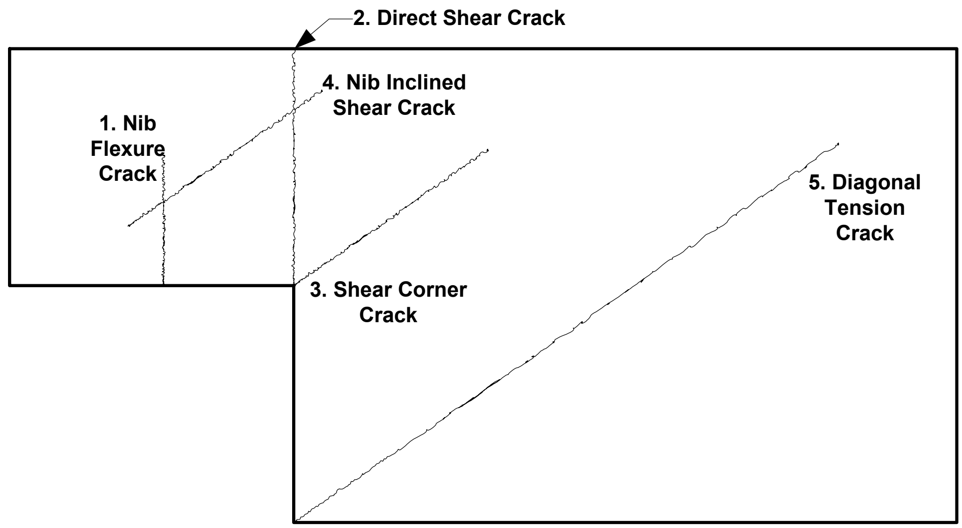


Figure 7.8.5 Crack Locations for Dapped End Double Tee Beams

Shear Zones

- Investigate the area near the supports for the presence of shear cracking. The presence of transverse cracks on the underside of the stems or diagonal cracks on the sides of the stem indicate the onset of shear failure. These cracks represent lost shear capacity and should be carefully measured.

Tension Zones

- Tension zones should be examined for flexure cracks, which would be transverse across the bottom of the stems and vertical on the sides. The tension zones are at the midspan along the bottom of the stem for both simple and continuous span bridges. Additional tension zones are located on the slab over the piers of continuous spans.

- Check for deteriorated concrete near the tension zones, which could result in the debonding of the tension reinforcement. This would include delamination, spalls, and contaminated concrete.

Diaphragms

- The diaphragms are designed as simple beams and should be inspected for flexure and shear cracks as well as typical concrete defects. Cracks in the diaphragms could be an indication of overstress or excessive differential deflection in the double tee beams.

Areas Exposed to Drainage

- If the roadway surface is bare concrete, check for delamination, scaling and spalls. The curb lines are most suspect. If the deck has an asphalt wearing surface, check for indications of deteriorated concrete such as reflective cracking and depressions.

- Check around scuppers or drain holes and deck fascias for deteriorated concrete.

- Check areas exposed to drainage for concrete spalling or cracking. This may occur at the ends of the beams where drainage has seeped through the deck joints.

Areas Over Traffic

- For grade crossing structures, check areas of damage caused by collision. This will generally be a corner spall with a few exposed rebars or prestressing strands.

Previous Repairs

- Examine areas that have been previously repaired. Determine if the repairs are in place and if they are functioning properly.

General

- Check for efflorescence from cracks and discoloration of the concrete caused by rust stains from the reinforcing steel. In severe cases, the reinforcing steel may become exposed due to spalling. Document the remaining cross section of reinforcing steel since section loss will decrease live load capacity. See Table 2.2.2 for concrete crack width guidelines.

- Using a string line, check for horizontal alignment and camber of the prestressed double tee beams. Signs of downward deflection usually indicate loss of prestress. Signs of excessive upward deflection usually indicate extreme creep and shrinkage.

7.8.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Pontis Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating. For prestressed double tees, the deck condition influences the superstructure component rating. When the deck component rating is 4 or less, the superstructure component rating may be reduced if the recorded deck defects reduce its ability to carry applied stresses associated with superstructure moments.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of slab and the underside. The information from the narrative and condition state summaries is then used to complete the element level condition report showing quantities at the correct rating value. Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a prestressed double tee beam bridge, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
012	Concrete Deck – Bare
013	Concrete Deck – Unprotected with AC Overlay
014	Concrete Deck – Protected with AC Overlay
018	Concrete Deck – Protected with Thin Overlay
022	Concrete Deck – Protected with Rigid Overlay
026	Concrete Deck – Protected with Coated Bars
027	Concrete Deck – Protected with Cathodic System
109	P/S Concrete Open Girder/beam

The unit quantity for the deck elements is “each”, and the entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2). The inspector must know the total slab surface area in order to calculate a percent deterioration and fit it into a given condition state description. The unit quantity for the prestressed double tee beam is meters or feet, and the total length of all beams must be placed in one of the four available condition states. Condition state 1 is the best possible rating for the deck or beam. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For structural cracks in the surface of bare slabs, the “Deck Cracking” Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a slab element, the “Soffit” Smart Flag, Element No. 359, can be used and one of five condition states assigned. For damage due to traffic impact, the “Traffic Impact” Smart Flag, Element No. 362, can be used and one of three condition states assigned.

Table of Contents

Section 7

Inspection and Evaluation of Common Concrete Superstructures

Topic 7.9 Prestressed I-Beams

7.9.1 Introduction

Prestressed I-beams and bulb-tees have been used since the 1950's. They have proven to be successful because of their material saving shapes and their light weights. The I or T shape allows a designer to have enough space to place the proper amount of reinforcement while reducing the amount of concrete needed (see Figure 7.9.1).

Figure 7.9.1 Prestressed I-Beam Superstructure

7.9.2 Design Characteristics

Prestressed I-beams and bulb-tees make economical use of material since most of the concrete mass is located away from the neutral axis of the beam.

Standard Shapes

Prestressed I-beams are shaped to provide minimum dead load with ample space for tendons. The most common prestressed concrete I-beam shapes are the AASHTO shapes used by most state highway agencies (see Figure 7.9.2). However, some highway agencies have developed variations of the AASHTO shapes to accommodate their particular needs.

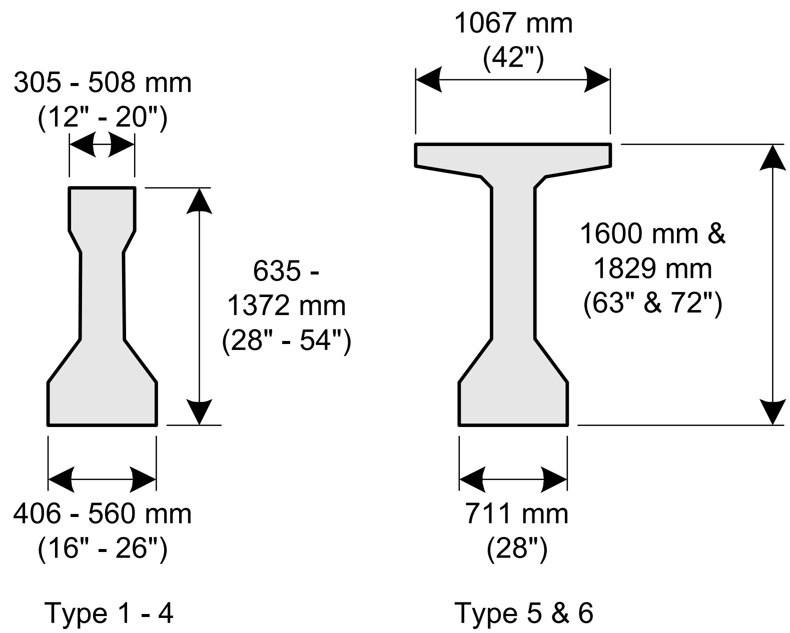


Figure 7.9.2 AASHTO Cross Sections of Prestressed I-Beams

Prestressed I-beams are used in spans ranging from 6 to 46 m (20 to 150 feet). They are generally most economical at spans from 18 to 35 m (60 to 115 feet).

Materials – Strength and Durability

Steel tendons with tensile strength as high as 1860 Mpa (270 ksi) are located in the bottom flange. These tendons are used to induce compression across the entire section of the beam prior to and during application of live load. This results in a crack free beam.

New technology may allow designers to reduce corrosion of prestressing strands. This reduction is made possible by using composite materials in lieu of steel. Carbon or glass fibers are two alternatives to steel prestressing strands that are being researched.

Concrete used is also of higher strength ranging from 34 Mpa (5,000 psi) compressive strength up to 68 Mpa (10,000 psi). In addition, concrete has a higher quality due to better control of fabrication conditions in a casting yard.

Reactive Powder Concrete (RPC) prestressed I-beams can come in an X shape (see Figure 7.9.3) or other concrete beam shapes. RPC prestressed beams may have an hourglass shape so as to take maximum advantage of RPC properties. Tested prestressed RPC I-beams are made without any secondary steel reinforcement and can carry the same load as a steel I-beam with virtually the same depth and weight.

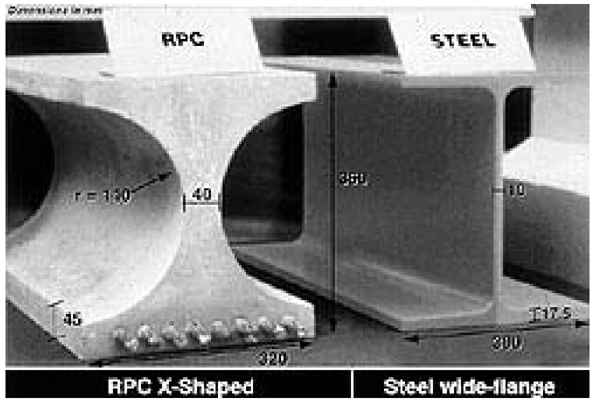


Figure 7.9.3 Reactive Powder Concrete (RPC) Prestressed X-Beam

Reactive Powder Concrete (RPC) creates a better bond between the cement and aggregate. This bond produces a material with a higher density, shear strength, and ductility than normal strength concrete. Silica fume is one of the ingredients in Reactive Powder Concrete that increases the strength. RPC prestressed I-beams are effective in situations where steel I-beams may be used, but are not effective where conventional strength prestressed concrete I-beams are strong enough.

Continuity

To increase efficiency in multi-span applications, prestressed I-beams can be made continuous for live load and/or to eliminate the deck joint. This is done using a continuous composite action deck and anchorage of mild steel reinforcement in a common end diaphragm (see Figure 7.9.4). Continuity has also been accomplished using posttensioning ducts cast into pretensioned I-beams. Tendons pulled through these ducts across several spans then are stressed for continuity. Cast-in-place concrete diaphragms are framed around the beams at the abutments and piers.

Figure 7.9.4 Continuous Prestressed I-Beam Bridge

Composite Action

The deck is secured to and can be made composite with the I-beam by the use of extended stirrups which are cast into the I-beam (see Figure 7.9.5).

Figure 7.9.5 Cast-In-Place Stirrups

Primary Members and Secondary Members

The primary members are the prestressed I-beams. The secondary members are the end diaphragms and the intermediate diaphragms. End diaphragms are usually full depth and located at the abutments or piers. Intermediate diaphragms are partial depth and are used within the span for longer spans (see Figure 7.9.6). Diaphragms are cast-in-place concrete or rolled steel sections and are placed at either the mid points or third points along the span.

Figure 7.9.6 Concrete End Diaphragm

Steel Reinforcement

Primary Reinforcement

Primary reinforcement consists of main tension steel and shear reinforcement or stirrups.

High Strength Steel

Main tension steel consists of pretensioned high strength prestressing strands or tendons placed symmetrically in the bottom flange and lower portion of the web. Strands are 9.5, 11.1, 12.7, or15.2 mm (3/8, 7/16, 1/2 or 0.6 inch) in diameter and are generally spaced in a 50.8 mm (2 inch) grid. In the larger beams main tension steel can include posttensioned continuity tendons which are located in ducts cast into the beam web (see Figure 7.9.7).

Mild Steel

Mild steel stirrups are vertical in the beam and located throughout the web at various spacings required by design (see Figure 7.9.7).

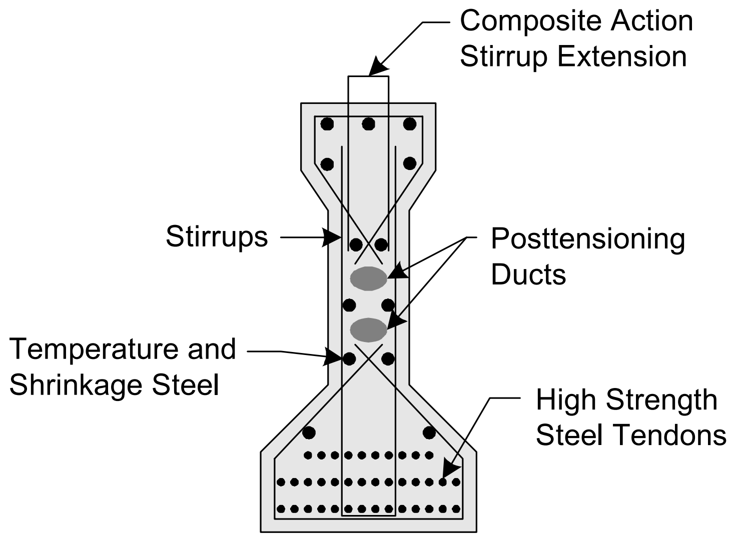


Figure 7.9.7 Prestressed I-Beam Reinforcement (Schematic)

Other Reinforcement

Other reinforcement includes mild steel temperature and shrinkage reinforcement which is longitudinal in the beam.

Composite Strands

Composite strands can be carbon fiber or glass fiber and are fairly new to the bridge prestressing industry. These strands are gaining acceptance due to the low corrosive properties compared to steel strands and will just be mentioned in this manual.

7.9.3 Overview of Common Defects

Common defects that occur on prestressed I-beams and bulb-tees include:

- Cracking
- Delamination
- Spalling
- Collision damage
- Overload damage
- Reinforcing/prestressing steel corrosion
- Stress corrosion
- Efflorescence
- Pop-outs

Refer to Topic 2.2 for a more detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.9.4 Inspection Procedures and Locations

Inspect a prestressed I-beam bridge and a bulb-tee bridge at the following locations using the following procedures:

Procedures

Visual

The inspection of concrete I-beams for cracks, spalls, and other defects is primarily a visual activity. However, hammers are primarily used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of I-beams with a hammer can be a tedious yet required operation. Many of the problems associated with concrete I-beams are caused by corrosion of the rebar. When the deterioration of a concrete I-beam progresses to the point of needing rehabilitation, an in-depth inspection of the I-beam is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic Methods
- Pulse Velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic13.2.3, include:

- Core Sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Advanced inspection techniques have been developed that can evaluate fatigue damage to steel reinforcement in a concrete member. The device is known as the magnetic field disturbance (MFD) system and can be used on reinforced and prestressed concrete. The system maps the magnetic field across the bottom and sides of the beam. A discontinuity in magnetized steel, such as a fracture in a rebar or a broken wire in a steel strand, produces a unique magnetic signal. While the research has been encouraging for detecting fatigue related damage, due to the significantly different magnetic signals for corroded reinforcing, MFD has not yet been demonstrated for detecting in-service corrosion damage.

Locations

Bearing Areas

- Check bearing areas for spalls or vertical cracks (see Figure 7.9.8). Spalls and cracks may be caused by corrosion of steel due to water leakage or restriction of thermal movement due to a faulty bearing mechanism. Spalling could also be caused by poor quality concrete (see Figure 7.9.9).
- Check for crushing of flange near the bearing seat.
- Check for rust stains which indicate corrosion of steel reinforcement.

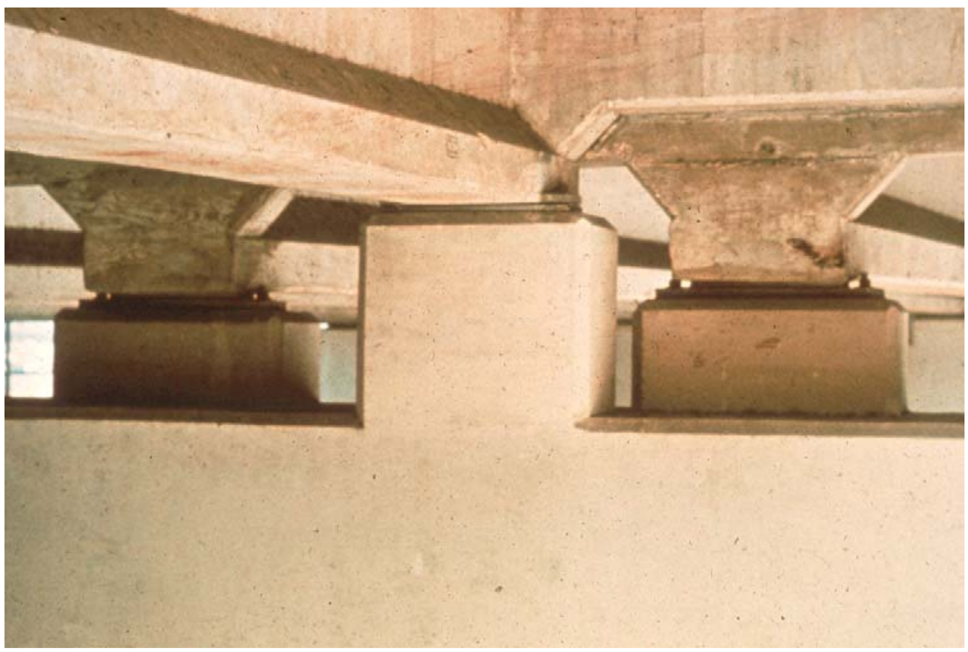


Figure 7.9.8 Bearing Area of a Typical Prestressed I-beam

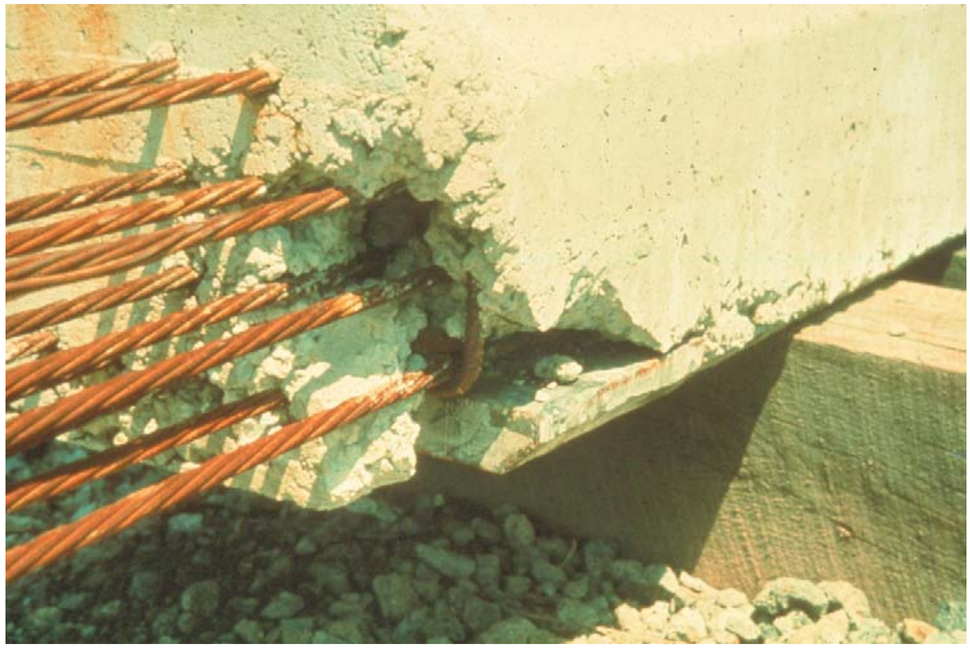


Figure 7.9.9 Spalling Due to Poor Concrete

Shear Zones

- Check beam ends and sections over piers for diagonal shear cracks in webs. These cracks will project diagonally upward from the support toward midspan.

Tension Zones

- Inspect the tension zones of the beams for structural cracks. Any crack should be carefully measured with an optical crack gauge and documented.

- Check for deteriorated concrete that could cause debonding of the tension reinforcement. This would include spalls, delamination, and cracks with efflorescence.

- Check bottom flange for longitudinal cracks that may indicate a deficiency of prestressing steel, insufficient cover, inadequate spacing, or possibly an overloading of the concrete due to use of prestressing strands that are too large.

- Check bottom flange at midspan for flexure cracks due to positive moment (see Figure 7.9.10). These cracks will be quite small and difficult to detect. An optical crack gauge should be used to measure any cracks found.

- For continuous bridges, check the deck area over the piers for flexure cracks due to negative moment.

- Check for rust stains from cracks, indicating corrosion of steel reinforcement or prestressing tendons.

- Check for exposed tension reinforcement and document section loss. Measurable section loss will decrease live load capacity. Exposed prestressing tendons are susceptible to stress corrosion and sudden failure.

Figure 7.9.10 Flexure Crack

Diaphragms

- Inspect the fixed diaphragms for spalling or diagonal cracking (see Figure 7.9.11). This is a possible sign of overstress caused by structure movement or excessive deflection.

- Investigate the intermediate diaphragms for cracking and spalling concrete. Flexure and shear cracks may indicate excessive differential movement of the I-beams.

Figure 7.9.11 Typical Concrete Diaphragm

Areas Exposed to Drainage

- Check around scuppers, inlets or drain holes for leaking water or deterioration of concrete (see Figure 7.9.12).

Figure 7.9.12 Leakage of Water at Inlet

Areas Over Traffic

- Check areas damaged by collision. A significant amount of prestressed concrete bridge deterioration and loss of section is due to traffic damage. Document the number of exposed and severed strands as well as the loss of concrete section. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss (see Figure 7.9.13).

Figure 7.9.13 Collision Damage on Prestressed Concrete I-Beam

Previous Repairs

Examine thoroughly any repairs that have been previously made. Determine if repaired areas are sound and functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement (see Figure 7.9.14).

Figure 7.9.14 Collision Damage Repair on Prestressed Concrete I-Beam. Note Epoxy Injection Ports

General

➢ Using a string line, check for horizontal alignment and camber of the prestressed beams. Signs of downward deflection usually indicates loss of prestress. Signs of excessive upward deflection usually indicates extreme creep and shrinkage.

7.9.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the element level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the prestressed I-beams. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a prestressed I-beam or bulb-T bridge, the AASHTO CoRe element is:

Element No.	**Description**
109	Concrete Open Girder/beam

The unit quantity for prestressed I-beams is meters or feet and the total length of all beams must be placed in one of the four available condition states. Condition state 1 is the best possible rating for the beam. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

Table of Contents

Section 7

Inspection and Evaluation of Common Concrete Superstructures

Topic 7.10 Prestressed Box Beams

7.10.1 Introduction

Prestressed box beams have become quite popular since the 1960's (see Figure 7.10.1). These precast members provide advantages from a construction and an economical standpoint by increasing strength while decreasing the dead load.

Figure 7.10.1 Typical Box Beam Bridge

7.10.2 Design Characteristics

General

Prestressed box beams are constructed having a rectangular cross section with a single rectangular void inside. Many prestressed box beams constructed in the 1950's have single circular voids. The top and bottom slabs act as the flanges, while the side walls act as webs. The prestressing reinforcement is placed in the bottom flange and into both webs (see Figure 7.10.2).

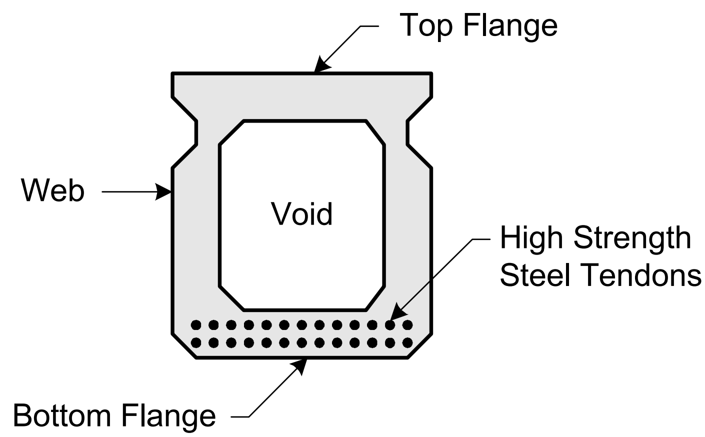


Figure 7.10.2 Schematic of a Typical Box Beam Cross-Section

Prestressed box beams are typically either 914 to 1219 mm (36 or 48 inches) wide. The depth of a box beam is typically 305, 432, 533, 686, 838, 914 or 1067 mm (12, 17, 21, 27, 33, 36, or 42 inches). Wall thickness ranges from 76 to 152 mm (3 to 6 inches).

The typical span length for prestressed concrete box beams ranges from 8 to 28 m (25 to 90 ft) depending on the beam configuration and spacing.

Design

Simple/Continuous Spans

Prestressed box beams can be simple or continuous spans. In the case of a simple span, the ends of the beams from span to span are not connected together at the support. An expansion joint is placed over the support in the concrete deck and the spans act independently. For continuous spans, the beam-ends from span to span are connected together by means of a cast-in-place concrete end diaphragm over the support. Mild steel reinforcement is placed in this diaphragm area and is spliced with steel reinforcement from the prestressed box beams. Continuous spans provide advantages such as eliminating deck joints, making a continuous surface for live loads, distributing live loads, and lowering positive moment.

Composite/Non-composite

Prestressed box beams can be composite or non-composite. By design, some prestressed box beams are constructed with the top of stirrups extending out of the top flange (see Figure 7.10.3). These stirrup tops are engaged when a cast-in-place concrete deck is placed and hardens. Once the concrete deck hardens, the deck becomes composite with the prestressed box beams. Prestressed box beams can also be non-composite. If the stirrups are not extended into the deck, the prestressed box beams cannot act integrally with the deck.

Figure 7.10.3 Box Beams at Fabrication Plant Showing Shear Connectors and Extended Rebar for Continuity

Construction

Box beams are constructed similar to I-beams, with high strength steel strands or tendons placed in the bottom flange and lower web area. The strength of the steel strands can be as high as 1860 MPa (270 ksi).

Concrete compressive strengths of 27 to 41 MPa (4000 to 6000 psi) are typically used in prestressed box beams, but concrete with ultimate strengths over 68MPa (10,000 psi) is available and becoming popular.

High performance concrete (HPC), which is a new type of concrete being used in bridge members, is designed to meet the specific needs of a specific project. The mix design is based on the environmental conditions, strength requirements, and durability requirements. This type of concrete allows engineers to design smaller, longer, and more durable members with longer life expectancies.

Advantages

Dead Load Reduction

Box beams are advantageous in that they allow for a reduced deck slab thickness, and therefore reduced dead load. Also, the voided beam reduces the dead load.

Construction Time Savings

Precast members are cast and cured in a quality controlled casting yard. Because box beams are precast, the construction process takes less time. When construction is properly planned, using precast members allows the structure to be erected with no down time due to concrete curing.

Shallow Depth

Prestressed box beams are designed with a typical maximum depth of 1067 mm

(42 inches). This shallow depth makes box beams viable solutions for field conditions that have tight vertical clearances.

Applications

There are two applications of prestressed box beams (see Figure 7.10.4):

- Adjacent box beams
- Spread box beams

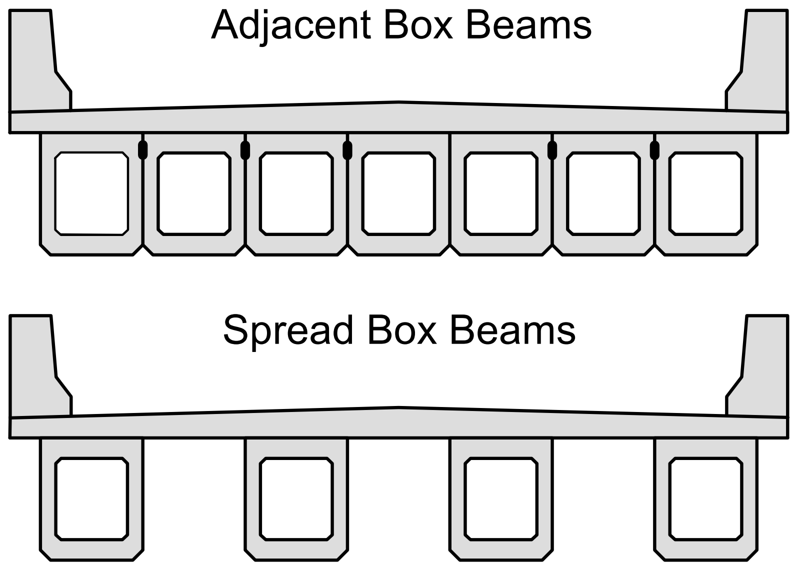


Figure 7.10.4 Applications of Prestressed Box Beams

Adjacent Box Beams

On an adjacent box beam bridge, the adjacent box beams are placed laterally side by side with no space between them. In some early applications, the top flange of each box is exposed and functions as the deck (see Figure 7.10.5). The practical span lengths range from 6.1 to 39.6 m (20 to 130 feet), with the most economical spans ranging from 12.2 to 27.4 m (40 to 90 feet).

Figure 7.10.5 Adjacent Box Beams Acting as the Deck

In modern longer span applications, the deck is typically a cast-in-place composite concrete deck. For composite decks, stirrups extend above the top of the box to provide the transfer of shear forces. For most shorter spans, nonstructural asphalt overlays with membrane waterproofing are applied.

This configuration of adjacent boxes is also called multiple boxes.

Monolithic Action

Like precast slab units, adjacent box beams are post tensioned laterally. This is generally done using threaded bars and lock nuts or tendons with locking wedges. Lateral post tensioning combined with grouted shear keys provides for monolithic action (see Figure 7.10.6).

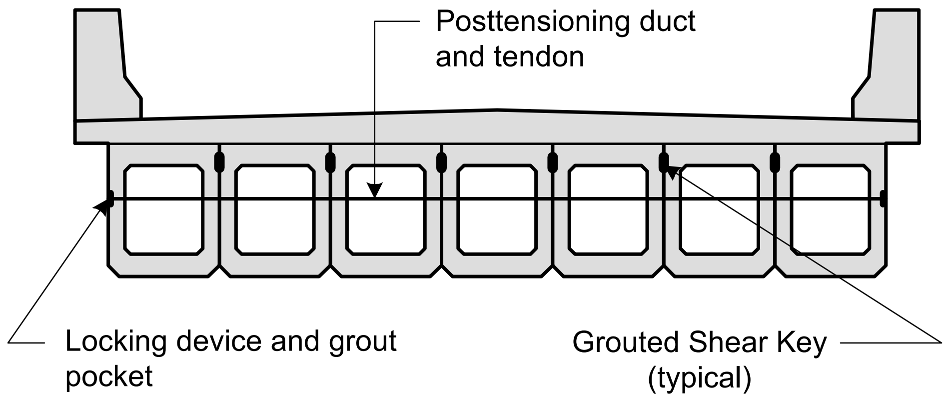


Figure 7.10.6 Schematic of Lateral Post-tensioning of an Adjacent Box Beam Bridge

Spread Box Beams

On a spread box beam bridge, the box beams are usually spaced from 610 to 1830 mm (2 to 6 feet) apart and typically use a composite cast-in-place concrete deck (see Figure 7.10.7). This application is practical for span lengths from 8 to 26 m (25 to 85 feet). Stay-in-place forms or removable formwork is used between the box beams to provide a support when the concrete deck is poured.

Figure 7.10.7 Underside of a Typical Spread Box Beam

All modern box beams have drain holes in the bottom to allow any moisture in the void to escape.

Primary Members and Secondary Members

The primary members of box beam bridges are the concrete box beams. External diaphragms are the only secondary members on box beam bridges, and they are only found on spread box beam bridges (see Figure 7.10.8). The diaphragms may be cast-in-place, precast, or steel and are placed at either the mid points or third points along the span.. They should be inspected as a beam. As with I-beams, they can provide restraint and act as a backwall. End diaphragms are located at the abutments and piers and can be full or partial depth. Intermediate diaphragms are located between bearing points and are usually partial depth.

Figure 7.10.8 External Diaphragms on a Spread Box Beam Bridge

Internal Diaphragms are considered a part of the prestressed box beams and not a secondary member (see Figure 7.10.9).

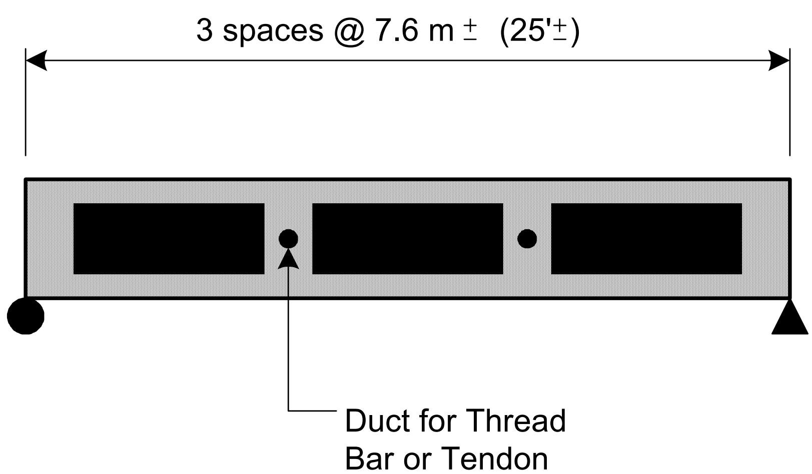


Figure 7.10.9 Schematic of Internal Diaphragms

Steel Reinforcement

Primary Reinforcement

Primary reinforcement consists of main tension steel and shear reinforcement or stirrups.

High Strength Steel

Main tension steel consists of high strength pretensioned prestressing strands placed in the bottom flange and lower web of the box beam. Depending on the age of the structure, the strand size will be 6, 10, 11 or 13 mm (1/4, 3/8, 7/16, or 1/2 inch) in diameter and spacing is normally 51 mm (2 inches) apart (see Figure 7.10.10). In some newer applications of prestressed box beams using HPC, 15mm (0.6-inch) strand sizes with a spacing of 51mm (2 inches) are used to fully implement the increased concrete strengths.

Mild Steel

Mild steel stirrups are placed vertically in the web at spacings required by design for shear reinforcement.

Other reinforcement

Other reinforcement includes transverse post-tensioning strands through the diaphragms and mild temperature and shrinkage reinforcement that runs longitudinal in the beam.

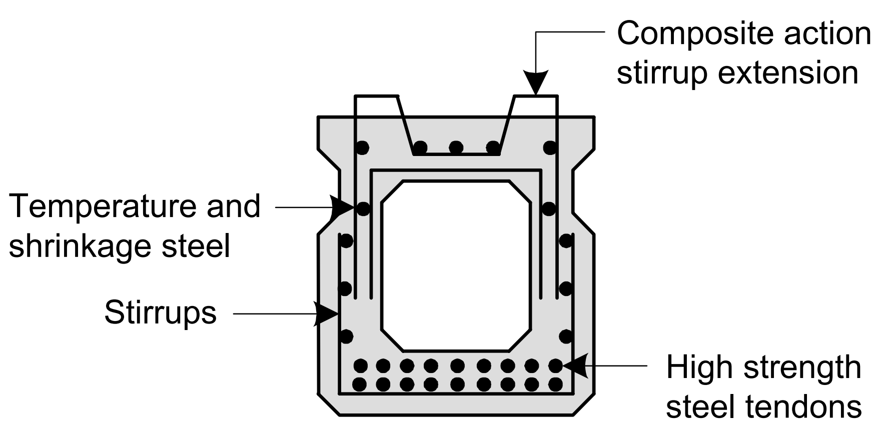


Figure 7.10.10 Schematic of Typical Prestressed Box Beam Reinforcement

Composite Strands

Composite strands can be carbon fiber or glass fiber and are fairly new to the bridge prestressing industry. Refer to Topic 7.9.2 for a brief explanation of composite strands.

7.10.3 Overview of Common Defects

Common defects that occur on prestressed box beams include:

- Cracking
- Delamination
- Spalling
- Collision damage
- Overload damage
- Reinforcing/prestressing steel corrosion
- Stress corrosion
- Efflorescence
- Pop-outs

Refer to Topic 2.2 for a more detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.10.4 Inspection Procedures and Locations

Since prestressed box beams are designed to maintain all concrete in compression, cracks are indications of serious problems. For this reason, any crack should be carefully measured with an optical crack gauge and documented.

Inspect a prestressed box beam bridge using the following procedures:

Procedures

Visual

The inspection of concrete box beams for cracks, spalls, and other defects is primarily a visual activity. However, hammers are primarily used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of box beams with a hammer is a tedious yet required operation. Many of the problems associated with concrete box beams are caused by corrosion of the rebar. When the deterioration of a concrete box beam progresses to the point of needing rehabilitation, an in-depth inspection of the box beam is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing

- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Bearing Areas

- The top of the beam-ends should be examined for horizontal or vertical cracks. These cracks indicate a deficiency of reinforcing steel. These cracks are caused by the stresses created at the transfer of the prestressing forces.

- Check bearing areas for spalls or vertical cracks. Spalls and cracks may be caused by corrosion of steel due to water leakage or restriction of thermal movement due to a faulty bearing mechanism (see Figure 7.10.11).

- Check for rust stains, which indicate corrosion of steel reinforcement (see Figure 7.10.12).

- Check the bottom of beams for longitudinal cracks originating from the bearing location. These cracks are sometimes caused by the unbalanced transfer of prestress force to the concrete, or by the accumulation of water inside the box, freezing and thawing (see Figure 7.10.13).

Figure 7.10.11 Spalled Beam Ends

Figure 7.10.12 Exposed Bars at End of Box Beam

Figure 7.10.13 Longitudinal Cracks in Bottom Flange at Beam

Shear Zone

- Check beam ends and sections over piers for diagonal shear cracks in webs. These cracks will project diagonally upward from the support toward midspan.

Tension Zones

- Investigate the lower portion of the beam, particularly at mid span, for flexure cracks. This indicates a very serious problem resulting from overloading or loss of prestress.

- Check for spalling, delamination and exposed reinforcing steel. Exposed strands fail prematurely due to stress corrosion (see Figure 7.10.14).

- Check for deteriorated concrete, which could cause debonding of the tension reinforcement. This would include spalls, delamination, and cracks with efflorescence.

- Check bottom flange for longitudinal cracks which may indicate a deficiency of prestressing steel, or possibly an overloading of the concrete due to use of prestressing forces that are too large.

- For continuous bridges, check the deck area over the supports for flexure cracks due to negative moment.

- An advanced inspection technique has been developed that can evaluate fatigue damage to steel reinforcement in a concrete member. The device is known as the magnetic field disturbance (MFD) system and can be used on reinforced and prestressed concrete. The system maps the magnetic field across the bottom and sides of the beam. A discontinuity in magnetized steel, such as a fracture in a rebar or a broken wire in a steel strand, produces a unique magnetic signal. While the research has been encouraging for detecting fatigue related damage, due to the significantly different magnetic signals for corroded reinforcing, MFD has not yet been demonstrated for detecting in-service corrosion damage.

Figure 7.10.14 Spall and Exposed Reinforcement

Diaphragms

- Inspect the fixed diaphragms for spalling or diagonal cracking. This is a possible sign of shear failure caused by structure movement.

- Investigate the intermediate diaphragms for cracking and spalling concrete. Flexure and shear cracks may indicate excessive differential moment of the box beams.

Areas Exposed to Drainage

- Examine between boxes in adjacent box beam bridges for leakage and rust stains. Look for reflective cracking in the traffic surface and individual beam deflection under live load. These problems indicate that the shear key between boxes has been broken and that the boxes are acting independently of each other (see Figure 7.10.15). These problems could also indicate the transverse post-tensioning is not acting as designed.

- Check drain holes for proper function as accumulated water can freeze and crack the webs of the beam. Be careful not to open the drain onto yourself.

Figure 7.10.15 Joint Leakage and Rust Stain

Areas Over Traffic

- Check areas damaged by collision. A significant amount of prestressed concrete bridge deterioration and loss of section is due to traffic damage. Document the number of exposed and severed strands as well as the loss of concrete section. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss (see Figure 7.10.16).

Figure 7.10.16 Close-up of Collision Damage

Previous Repairs

- Examine thoroughly any repairs that have been previously made. Determine if repaired areas are functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

General

- Examine the sides of the beams for cracks. Adjacent box beam side surfaces are visible only on the fascias. For interior beams, inspect the bottom chamfers for cracks, which may extend along the sides of the beams.

- Using a string line, check for horizontal alignment and camber of the prestressed beams. Signs of downward deflection usually indicates loss of prestress. Signs of excessive upward deflection usually indicates extreme creep and shrinkage.

- Note the presence of surface irregularities caused by burlap folds used in the old vacuum curing process. This dates the beam construction to the early 1950's and should alert the inspector to possible deficiencies common in early box beams, such as inadequate or non-existent drainage openings and strand cover (see Figure 7.10.17).

Figure 7.10.17 Burlap Fold Depressions in an Early 1950's P/S Box Beam

7.10.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the element level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the prestressed box beam. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a prestressed box beam bridge, the AASHTO CoRe element is:

Element No.	**Description**
109	Concrete Open Girder/beam

The unit quantity for prestressed box beams is meters or feet and the total length of all beams must be placed in one of the four available condition states. Condition state 1 is the best possible rating for the beam. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

This page intentionally left blank

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

Topic 7.11 Concrete Box Girders

7.11.1 Introduction

The box girder bridge is the current state-of-the-art bridge type for concrete. Using a trapezoidal box shape with cantilevered top flange extensions, a single box girder combines mild steel reinforcement and high strength post-tensioning tendons into a cross section capable of accommodating an entire roadway width. Designs are common, although not yet standardized, for both segmental and monolithic box girder construction. In addition, reinforced concrete (mild steel reinforcement) box girder bridges were once commonly constructed for short spans, and many of those bridges still exist today.

Older box girder bridges can also be cast-in-place with mild steel reinforcement or post-tensioned (see Figures 7.11.1 and 7.11.2). This bridge type is popular in midwest states (e.g., Wisconsin, Minnesota, Michigan and Kansas).

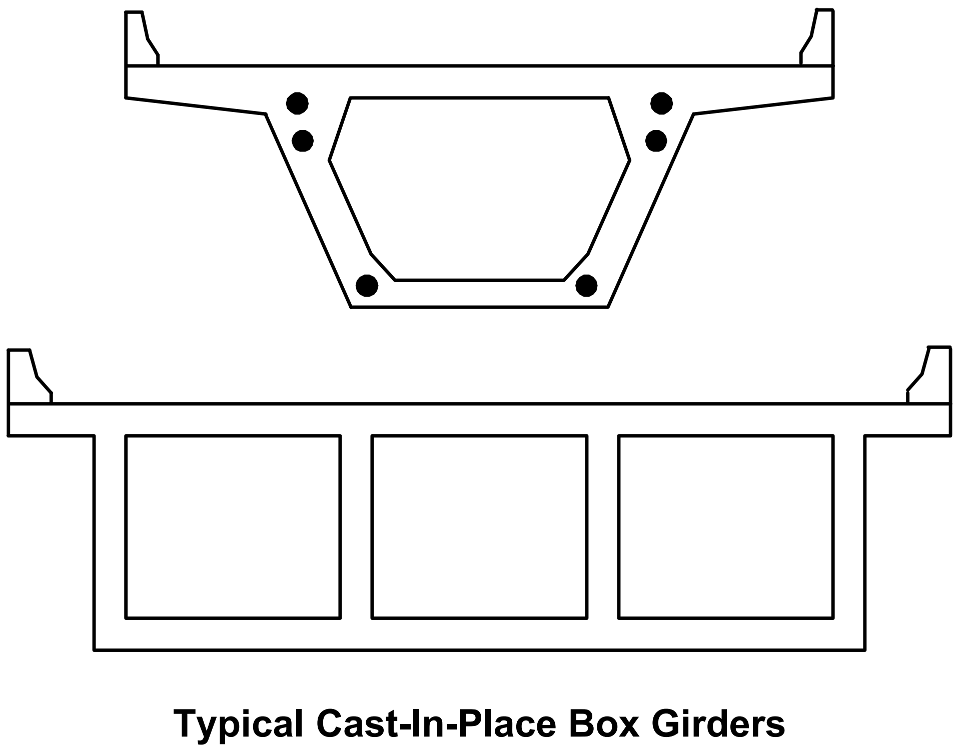


Figure 7.11.1 Typical Cast-in-place Box Girder Cross Section

Figure 7.11.2 Typical Cast-in-place Concrete Box Girder Bridge

7.11.2 Design Characteristics

Concrete Box Girder

For wide roadways, the box portion generally has internal webs and is referred to as a multi-cell box girder (see Figure 7.11.3). Concrete box girder bridges are typically either single span or continuous multi-span structures. Spans can have a straight or curved alignment and are generally in excess of 46 m (150 feet) (see Figure 7.11.4).

The following description applies to monolithic box girder construction only. A detailed description of segmental concrete bridges appears later in this Topic.

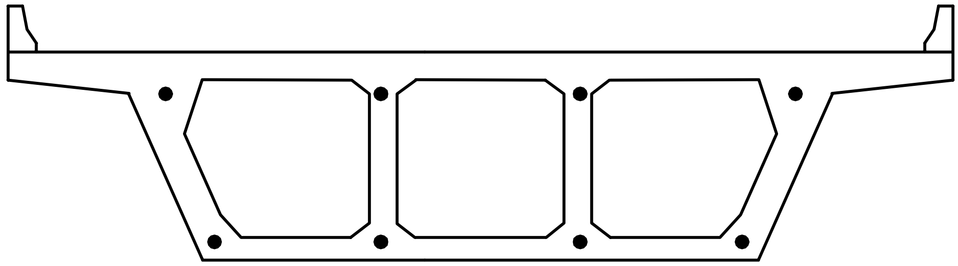


Figure 7.11.3 Multi-cell Girder

Figure 7.11.4 Typical Cast-in-place Concrete Box Girder Bridge

Construction Methods

The two basic construction techniques used for cast-in-place monolithic box girders are high level casting and at-grade casting.

High Level Casting

The high level casting method employs formwork supported by falsework. This technique is used when the structure must cross an existing feature, such as a roadway, railway, or waterway (see Figure 7.11.5).

Figure 7.11.5 High Level Formwork Support Scaffolding

At-grade Casting

The at-grade casting method employs formwork supported by fill material or the existing ground. When the construction is complete, the fill beneath the bridge is removed. This technique is used when the structure is crossing, or is part of a new highway system or interchange (see Figures 7.11.6 and 7.11.7). The at-grade casting method is common in Arizona and other southwestern states.

Figure 7.11.6 At-grade Formwork with Post-tensioning Ducts

Figure 7.11.7 Box Girder Bridge Construction Using At-grade Forming

Primary Members

For box girder structures, the primary member is the box girder. When a single-cell box girder design is used, the top flange or deck slab, the bottom flange, and both side walls are all primary elements of the box girder (see Figure 7.11.8). The top flange is considered an integral deck component.

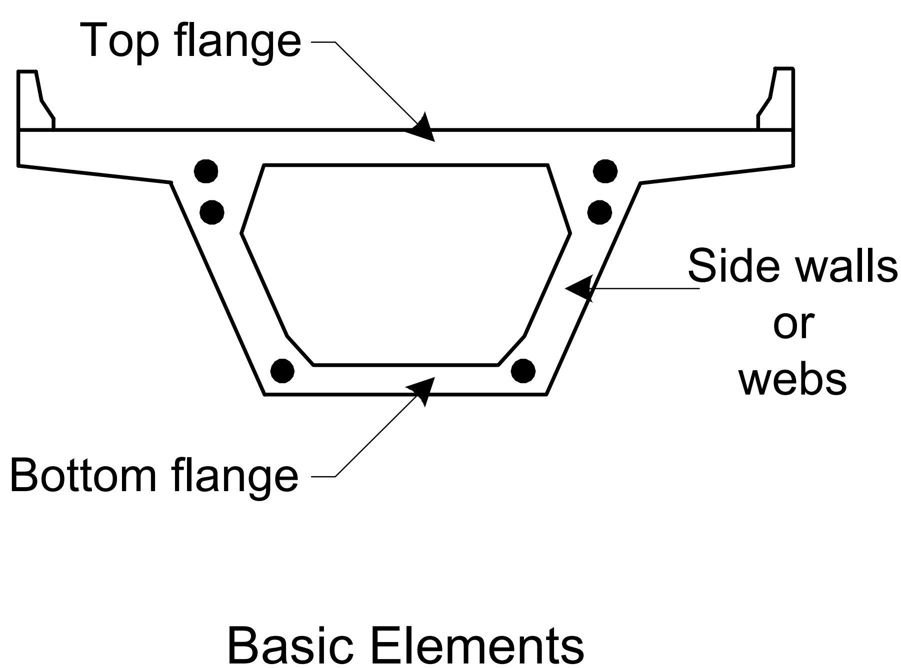


Figure 7.11.8 Basic Elements of a Cast-in-place Box Girder

In some multi-cell box girder applications, the top flange or deck slab must be removable for future replacement. The top flange in these cases functions similarly to a composite deck slab and is in fact considered a separate deck component. Most exterior webs have higher stress levels than interior webs, but the interior webs of the box also play a significant role in the girder (see Figure 7.11.9).

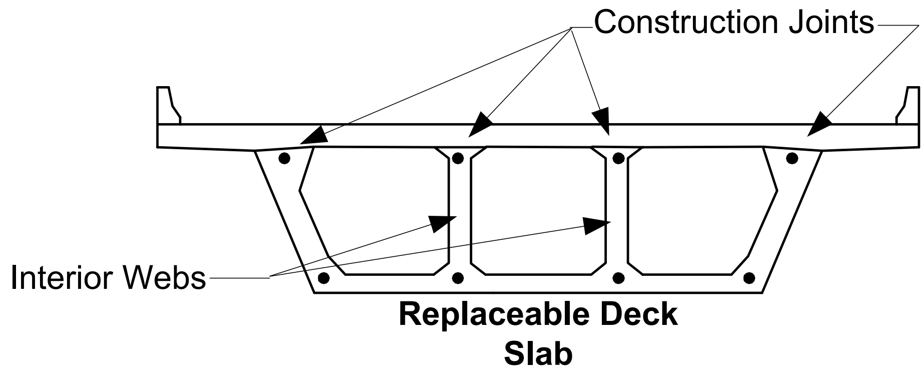


Figure 7.11.9 Replaceable Deck Slab on a Multiple Cell Cast-in-place Box Girder

Steel Reinforcement

Box girder structures use a combination of mild steel reinforcement and high strength post tensioning steel tendons (see Figure 7.11.10). Shear reinforcement is provided to resist standard beam action shear. For curved girder applications, torsional shear reinforcement is sometimes required. This reinforcement is provided in the form of additional stirrups.

Flexure reinforcement is provided in the top and bottom flanges of the box girder as necessary (bottom flange at midspan in areas of positive moment and top flange over supports in areas of negative moment). However, because of the design span lengths, mild steel reinforcement does not have sufficient strength to resist all of the tension forces.

To reduce these tensile stresses to acceptable levels, prestressing of the concrete is introduced through post-tensioning. Galvanized metal and polyethylene ducts are placed in the forms at the desired location of the tendons. When the concrete has cured to an acceptable strength level, the tendons are installed in the ducts, tensioned, and then grouted (see Figure 7.11.11).

Special “confinement” reinforcement is also required at the anchorage locations to prevent cracking due to the large transfer of force to the surrounding concrete.

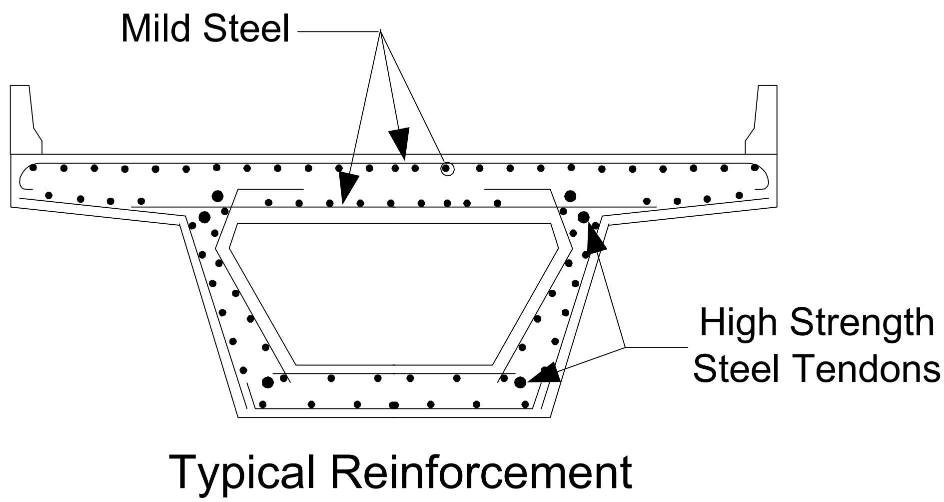


Figure 7.11.10 Longitudinal Reinforcement in a Concrete Box Girder

Figure 7.11.11 Formwork with Post-tensioning Duct End Fittings and Spiral Anchorage Reinforcement

Segmental Box Girder

Many current box girders are built using segmental construction. A segmental concrete bridge is fabricated piece by piece. These pieces, or segments, are post-tensioned together during the construction of the bridge (see Figure 7.11.12 and 7.11.13). The superstructure can be constructed of precast concrete or cast-in-place concrete. Several characteristics are common to most segmental bridges:

- Used for long span bridges
- Generally comprised of box girder segments
- Used when falsework is undesirable or cost-prohibitive such as bridges over steep terrain or environmentally sensitive areas.

- For most bridges, each segment is the full width and depth of the bridge; for very wide decks, many segmental box girders may consist of two-cell boxes or adjacent single boxes
- The length of the segments is determined by the construction methods and equipment available to the contractor
- Depending on the construction method, a new segment may be supported from previously erected segments

Figure 7.11.12 Segmental Concrete Bridge

Figure 7.11.13 Close-up of Segment

Because most erection methods for segmental concrete bridges involve relatively small amounts of falsework, this form of bridge construction is attractive for limited access and environmentally sensitive project sites.

Segment Configurations

The majority of concrete segmental bridges use a box girder configuration (see Figure 7.11.14). The box girder is preferred due to the following:

- The top slab can be used as the roadway traffic surface
- The wide top and bottom slabs provide large compression areas
- The box shape provides excellent torsional rigidity
- The box shape lends itself well to horizontally curved alignments

The typical box girder section will have the following elements:

- Top slab
- Bottom slab
- Web walls
- Interior web walls (multi-cell)

Single box girder segments are usually used, although spread multiple boxes can be used if they are connected together by external diaphragms.

Segmental Classification

Individual segments can either be cast-in-place or precast concrete.

Cast-in-Place

Cast-in-place segmental construction is generally performed by supporting the segment formwork from the previous cast segment. Reinforcement and concrete is placed and the segment is cured. When the newly cast segment has reached sufficient strength, it is post-tensioned to the previous cast segment. This process proceeds until the bridge is completed.

Precast

Precast segmental construction is performed by casting the individual segments prior to erecting them. The actual casting can take place near the project location or at a fabrication plant. Once the precast segment is positioned adjacent to the previous placed segment, it is post-tensioned in the same manner as the cast-in-place segment previously mentioned. This process also repeats itself until the bridge is completed (see Figure 7.11.15).

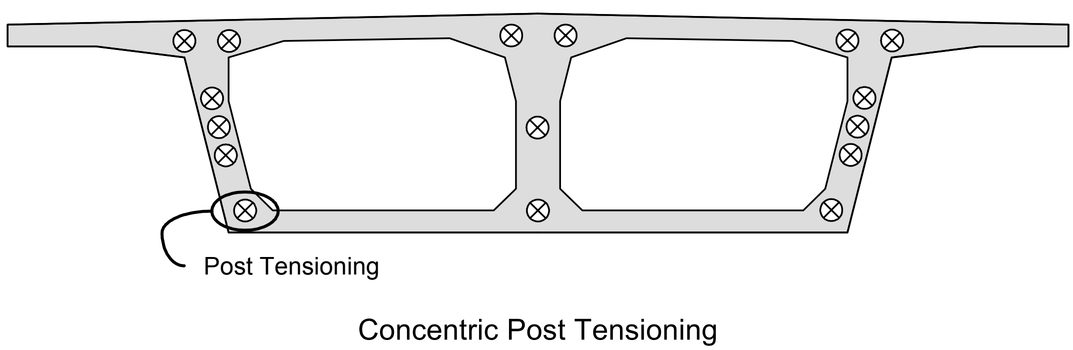


Figure 7.11.14 Box Girder

Figure 7.11.15 Box Girder Segment

Precast construction lends itself well to repetitive operations and associated efficiencies. Fabrication plant operations also tend to offer higher degrees of quality control than field operations associated with cast-in-place construction. Precast construction must be monitored and controlled to ensure the proper fit in the field with regards to vertical and horizontal alignment. In order to control this situation, match casting is usually employed. Match casting utilizes the previous segment as part of its formwork to ensure a proper mating segment.

Cast-in-place construction frequently does not enjoy the efficiencies of precast construction but does have the advantage of relatively easy field adjustments for controlling line and grade of alignment.

Construction Methods

Balanced Cantilever

This form of construction requires individual segments to be placed symmetrically about a pier. As the segments are alternately placed about the pier, the bending moments induced into the pier by the cantilever segments tend to balance each other. Once the mid-span is reached, a closure segment is cast with the previously erected half-span from the adjacent pier. This procedure is repeated until all the spans have been erected (see Figure 7.11.16 and 7.11.17). Both cast-in-place and precast construction is suitable for this form of construction (see Figure 7.11.18).

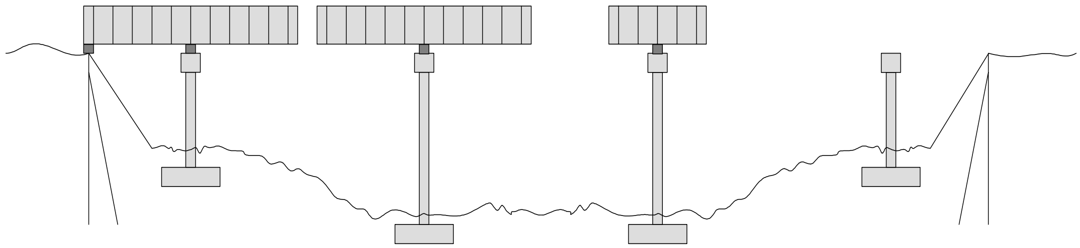


Figure 7.11.16 Balanced Cantilever Method

Figure 7.11.17 Balanced Cantilever Construction

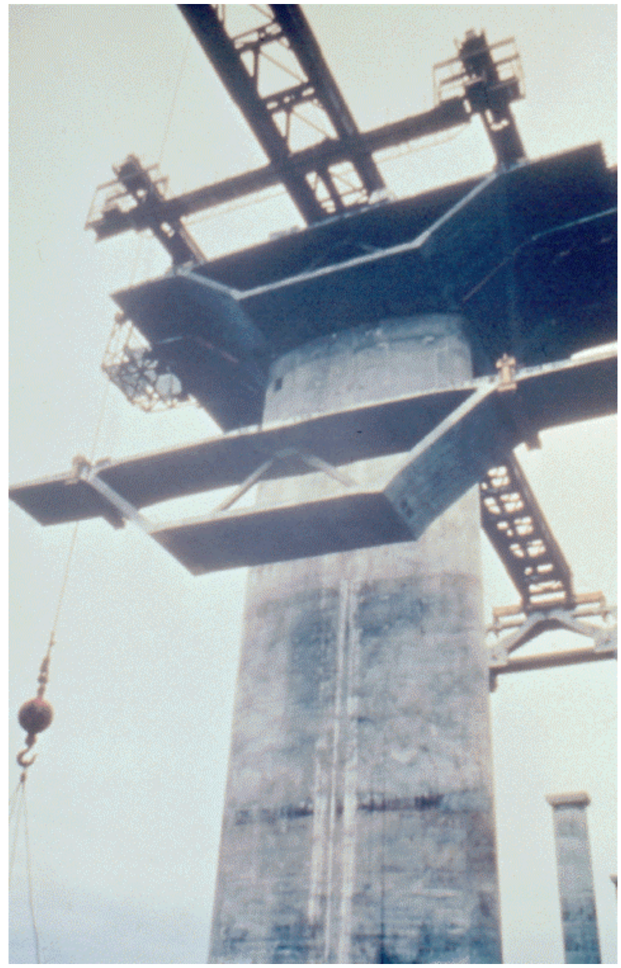


Figure 7.11.18 Balanced Cantilever Construction

Span-by-span Construction

This form of construction may require a temporary steel erection truss or falsework, which spans from one pier to another. The erection truss provides temporary support of the individual segments until they are positioned and post-tensioned into their final configuration. This type of construction allows a total span to be erected at one time. Once the span has been completed the erection truss is removed and repositioned on the next adjacent span. This procedure is repeated until all the spans have been erected (see Figure 7.11.19 and 7.11.20).

Epoxy bonding adhesive is applied to the match-cast joints during initial erection.

Figure 7.11.19 Span-by-Span Construction (with Erection Truss)

Figure 7.11.20 Span-by-span Close-up (with Erection Truss)

The entire span may also be assembled or cast on the ground, or on a floating barge. The span is raised to final position with lifting jacks and made continuous with the previously placed pier segments by closure pours and longitudinal post-tensioning. Both cast-in-place and precast construction is suitable for this form of construction (see Figure 7.11.21).

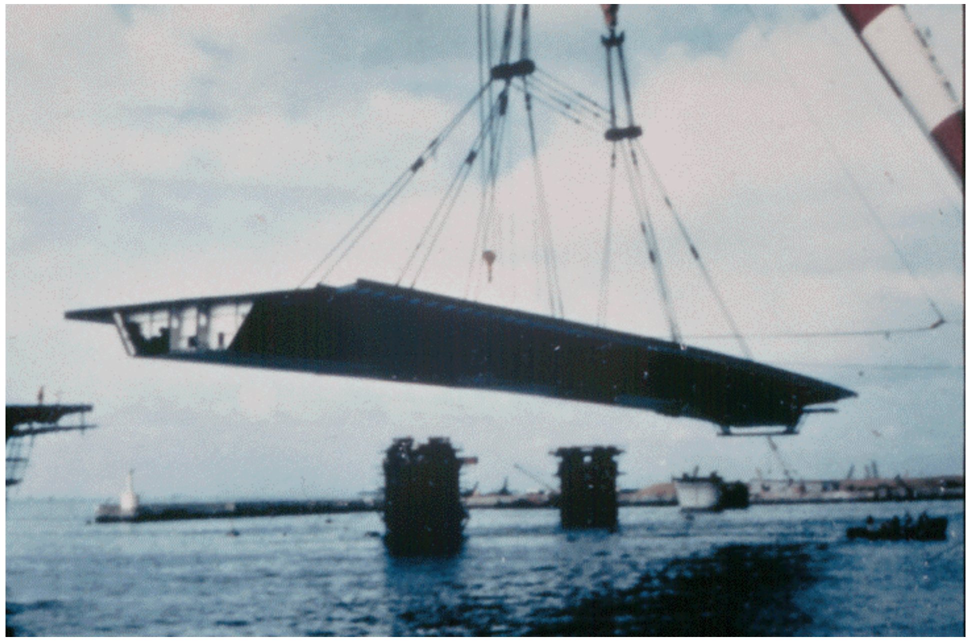


Figure 7.11.21 Span-by-span Total Span Erection (Lifting)

Progressive Placement Construction

This form of construction is much like the span-by-span construction described above. Construction proceeds outward from a pier towards an adjacent pier and once completed, the process is repeated in the next span and so on until the bridge is completed. Because of the large bending forces associated with this type of construction, temporary bents or erection cables tied off to a temporary erection tower are often employed (see Figure 7.11.22).

Figure 7.11.22 Progressive Placement Construction

Incremental Launching Construction

This form of construction permits the individual segments to be fabricated or positioned behind an abutment, post-tensioned, and then launched forward towards an adjacent pier by means of hydraulic jacks. This process is repeated until the entire bridge is constructed (see Figure 7.11.23).

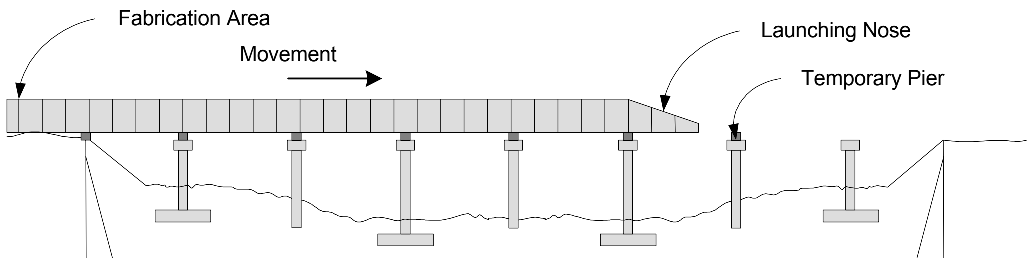


Figure 7.11.23 Incremental Launching Method

To aid the advancement and guide the already completed segments, a steel launching nose is attached to the leading segment. If the spans become very large, temporary bents are often used to reduce the large negative bending effects developed in the completed cantilever segments (see Figure 7.11.24).

Figure 7.11.24 Incremental Launching Overview (Note Temporary Pile Bent)

Both cast-in-place and precast construction is suitable for this type of construction.

7.11.3 Overview of Common Defects

Common defects that occur on concrete box girder bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs

- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.11.4 Inspection Procedures and Locations

Procedures

Visual

The inspection of concrete box girders for cracks, spalls, and other defects is primarily a visual activity. However, hammers are primarily used to detect areas of delamination. A delaminated area will have a distinctive hollow "clacking" sound when tapped with a hammer. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of box girders with a hammer is a tedious yet required operation. Many of the problems associated with concrete box girders are caused by corrosion of the rebar. When the deterioration of a concrete box girder progresses to the point of needing rehabilitation, an in-depth inspection of the box girder is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods

- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.2, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Concrete Box Girder

The inspection of a box girder bridge requires a clear understanding of the girder function. This requires a thorough review of design or as-built drawings prior to the inspection and a realization of the high stress regions peculiar to a particular structure. Because of the complexities of box girders, many agencies develop an inspection and maintenance manual for a structure, which is written by the structural designer.

Arguably, the most important inspection a box girder will receive is the first one. This inspection will serve as a benchmark for all future inspections. Since it is so important, the initial inspection should be scheduled as early as possible after the construction of the bridge. Because of the complex nature of the box girder, all surfaces on the interior and exterior of the girder require visual examination.

Inspecting a concrete box girder bridge is similar to the procedure discussed in Topic 5.2.6, Concrete Decks, and includes the following specific procedures:

Bearing Areas

- The effects of temperature, creep, and concrete shrinkage may produce undesirable conditions at the bearings. Check the bearing areas and the bearings for proper movement and movement capability (see Figure 7.11.25).

Figure 7.11.25 Bearing Area of a Cast-in-place Box Girder Bridge

Shear and Tension Zones

- Shear **-** These cracks will occur in the webs of the girder and will be pronounced adjacent to abutments and piers. They will be at approximately a 45 degree angle when compared to the longitudinal axis of the girder and extend from the support toward mid-span (see Figure 7.11.26).

Figure 7.11.26 Shear Crack Location Near an Abutment

- Direct Tension - Tension cracks will appear as a series of parallel cracks running transverse to the longitudinal axis of the bridge. The cracks can possibly be through the entire depth of the box girder section. Cracks will probably be spaced at approximately 1 to 2 times the minimum thickness of the girder elements.

- Flexure - These cracks will appear in the top flange at pier locations and on the bottom flange at mid-span regions. The extent of cracking will depend on the intensity of the bending being induced. Flexure cracks will normally propagate to an area around the half-depth of the section. Flexural cracks found in post-tensioned members should alarm the inspector and be examined very carefully. This could indicate that the member is overstressed. Accurately identify the location of the crack, the dimensions of the crack, and the severity of the crack.

- Flexure-shear - These cracks will appear close to pier support locations. They will begin on the bottom flange oriented transverse to the longitudinal axis of the bridge. The cracking will extend up the webs approximately 45 degrees to the horizontal and toward mid-span.

- Inspect the top side of the top flange for longitudinal flexure cracking directly over interior and exterior girder walls. Inside the box, examine the bottom of the top flange for longitudinal flexure cracking between the girder walls. Any efflorescence or leakage through the top flange should be documented.

- The girder should be inspected throughout for flexure and shear cracks as well as prestress-induced cracks. Some shrinkage cracks are to be expected. Likewise, although post-tensioned, some small working cracks will be present. As with all prestressed concrete members, any cracks should be carefully measured with an optical crack gauge and its location, length, and width documented. For field notes, one might want to substitute the following descriptions for various crack widths:

Hairline	=	0.1 mm (Less than 0.004 inches)
Narrow	=	0.1 to 0.23 mm (0.004 to 0.009 inches)
Medium	=	0.25 to 0.76 mm (0.010 to 0.030 inches)
Wide	=	0.76 mm (Greater than 0.030 inches)

(Note: these crack widths are for prestressed members only)

Anchor Blocks

- Anchor blocks contain the termination of the post-tensioning tendons. Very large concentrated loads are developed within these blocks. They have a tendency to crack if not properly reinforced. The cracking will be more of a splitting failure in the web and would be oriented in the direction of the post-tensioning tendon (see Figure 7.11.27).

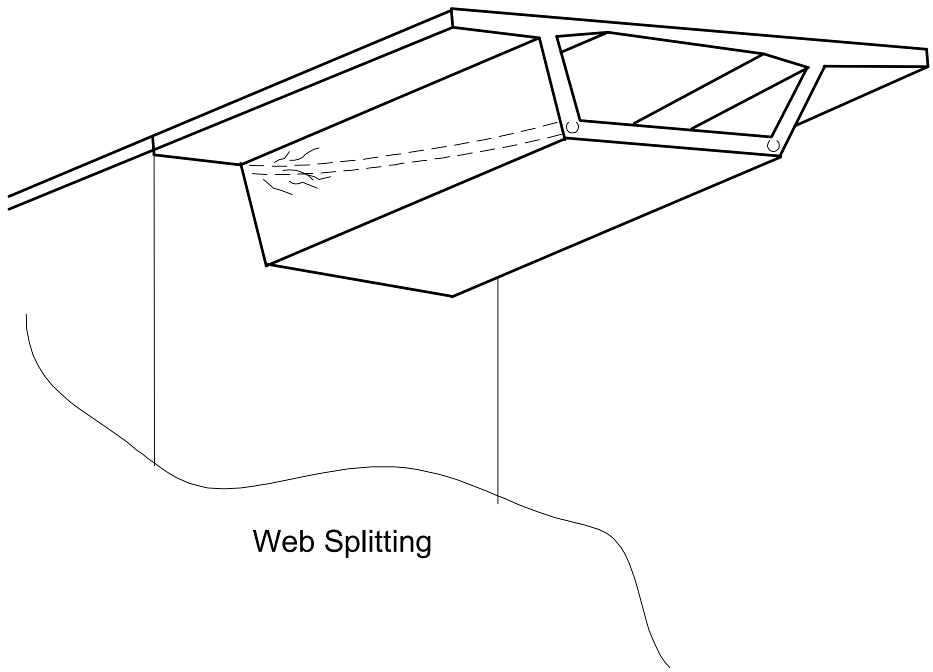


Figure 7.11.27 Web Splitting near an Anchorage Block

Areas Exposed to Drainage

- Examine the girder for any delaminations, spalling, or scaling which may lead to exposure of reinforcing steel. Areas exposed to drainage should receive special attention.

Areas Exposed to Traffic

- Check areas damaged by collision. A significant amount of concrete box girder bridge deterioration and loss of section is due to traffic damage. Document the number of exposed and severed strands as well as the loss of concrete section. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss.

Areas Previously Repaired

- Examine thoroughly any repairs that have been previously made. Determine if repaired areas are sound and functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

Miscellaneous Areas

- Cracks Caused by Torsion **-** This type of cracking will occur in both the slabs and webs of the box girder due to the twisting motion induced into the section. This cracking is very similar to shear cracking and will produce a helical configuration if torsion alone was present. Bridge structures most often will not experience torsion alone; rather bending, shear and torsion will occur simultaneously. In this event, cracking will be more pronounced on one side of the box due to the additive effects of all forces

- Thermal Effects - These cracks are caused by non-uniform temperatures between two surfaces located within the box girder. Cracking will typically be transverse in the thinner slabs of the box and longitudinal near changes in cross section thickness (see Figure 7.11.28).

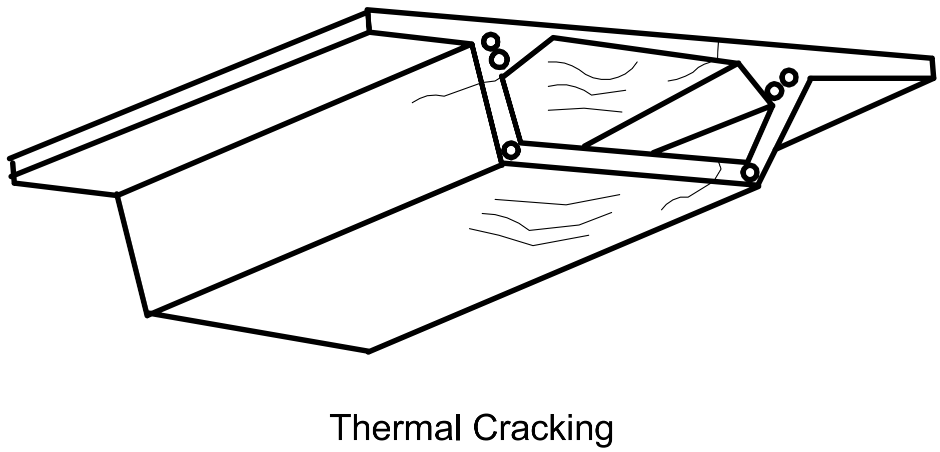


Figure 7.11.28 Thermal Cracking

- Post-tensioning - Cracking can occur along any of the lines of post-tensioning tendons. For this reason it is important for the inspector to be aware of where tendons are located in the box section (see Figure 7.11.29). This cracking may be the result of a bent tendon or a misaligned tendon with insufficient concrete cover. Shrinkage of concrete adjacent to large tendons has also caused this type of cracking.

Figure 7.11.29 Post-tensioning Tendon Duct

- Overstress **-** Older cast-in-place box girder interiors should be inspected to verify that inside forms left in place do not provide unintentional load paths, which may result in overloading elements of the box (see Figure 7.11.30).

Figure 7.11.30 Interior Formwork Left in Place

- Structure Alignment - An engineering survey needs to be performed at the completion of construction and a schedule for future surveys established. The results of these surveys will aid the bridge engineer in assessing the behavior and performance of the bridge. Permanent survey points at each substructure and at each mid-span should be established. Likewise, several points need to be set at each of these locations in the transverse direction across the top slab. During the inspection, the inspector should:

- Inspect the girder for the proper camber by sighting along the fascia of the top flange.
- On curved box girders, check for irregularities in the superelevation of the top flange, which could indicate torsional distress.

- Cracking Along the Line of Tendons - Cracking can occur along any of the lines of post-tensioning tendons. This is why it is important for the inspector to be aware of where the tendons are located within the box girder section. This cracking may be the result of a bent tendon or a misaligned tendon with insufficient concrete cover. Shrinkage of the concrete adjacent to large tendons has also caused this type of cracking.

- Radial Cracking - Post-tensioning tendons can be aligned vertical, horizontal or both depending on the vertical and horizontal geometry of the finished structure. The tendons produce a component of force normal to the curvature of their alignment. The result of this force can be cracking or spalling of the concrete elements that contain these tendons. This type of distress is localized to the tendon in question, but can occur virtually anywhere along the length of the tendon. Joints of match cast precast segments are particularly sensitive to this type of cracking.

- Inspection of the roadway surface for cracking, spalling, twisting, and deformation; the presence of these defects can increase the impact effect of traffic; also this may be of great significance since, in many segmental bridges, the top of the structural member is the riding surface.

- Investigation of unusual noises, such as banging and screeching, which may be the result of structural distress.

- Observation and recording of data from any monitoring instrumentation (e.g., strain gauges, displacement meters, or transducers) that has been installed on or within the bridge.

Segmental Box Girder

In addition to the inspection locations and procedures for concrete box girders, there are several special elements that are unique to segmental bridges. The bridge inspector should be familiar with these special elements (see Figure 7.11.31).

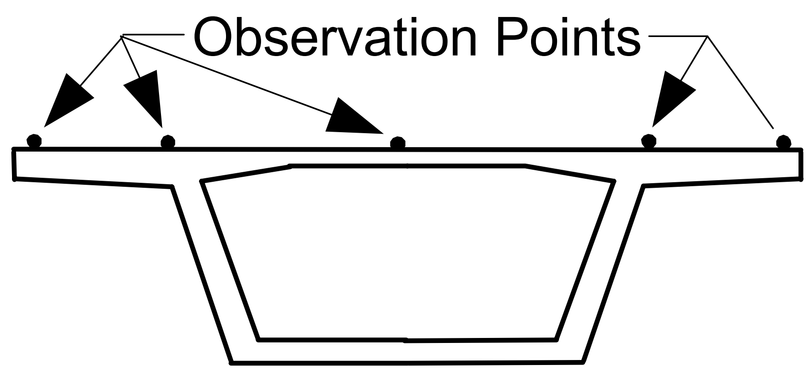


Figure 7.11.31 Location of Observation Points Across the Deck

Inspecting a segmental box girder bridge is similar to the procedures mentioned above for concrete box girders, and includes the following specific procedures:

Bearing Areas

- Due to the inherent behavior of prestressed concrete structures, the effects of temperature, creep and shrinkage of the concrete may produce undesirable conditions to the bearings. These undesirable conditions take the form of distorted elastomeric bearings or loss of movement to mechanical bearings. Additionally, the areas where bearings interface with the bottom flange of the box girder need special attention. Large vertical forces from the superstructure are required to be transmitted to the bearings and, therefore, sizable bearing stresses are produced in these areas (see Figure 7.11.32).

Figure 7.11.32 Box Girder Bearings at Intermediate Pier

Shear and Tension Zones

- Inspect both the interior and the exterior surfaces of the box girder. The inspection procedures for shear and tension zones in segmental box girder bridges are the same as for concrete box girder bridges. Examples of cracking in segmental box girder bridges are shown in Figures 7.11.33 to 7.11.37.

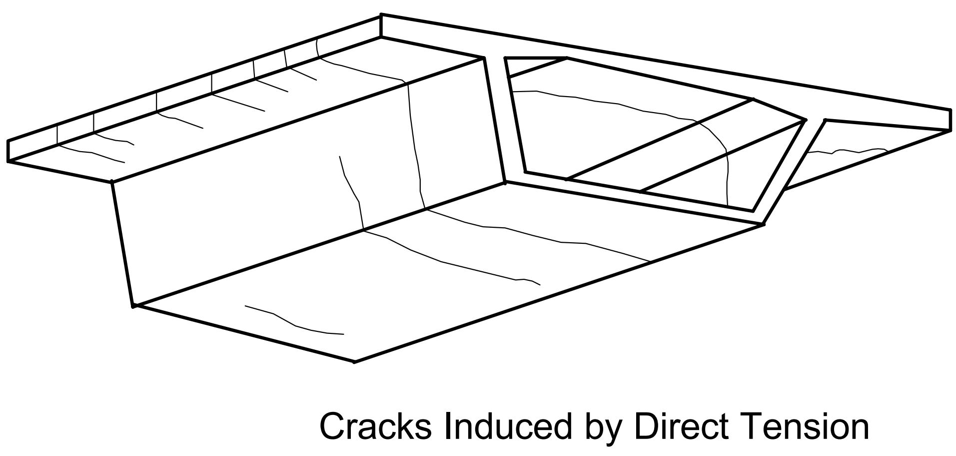


Figure 7.11.33 Box Girder Cracks Induced by Direct Tension

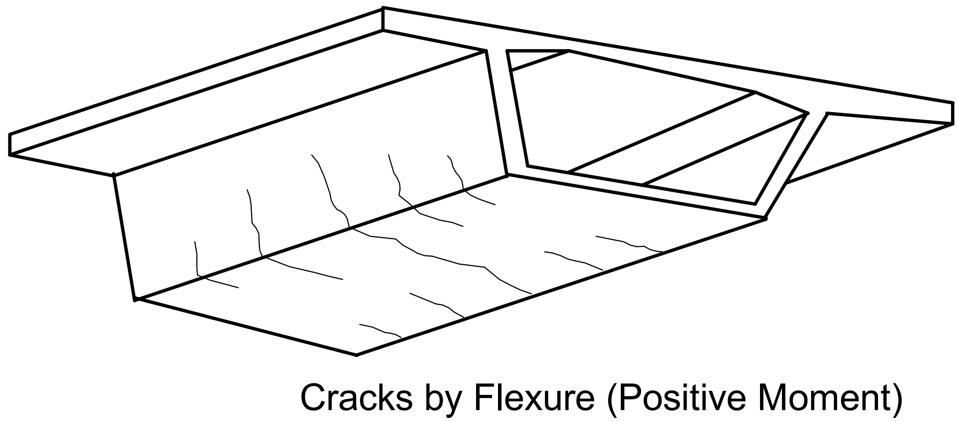


Figure 7.11.34 Box Girder Cracks Induced by Flexure (Positive Moment)

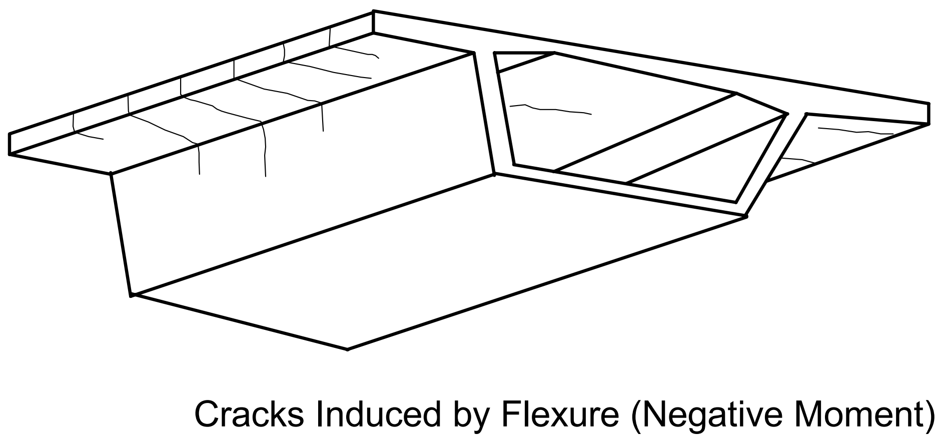


Figure 7.11.35 Box Girder Cracks Induced by Flexure (Negative Moment)

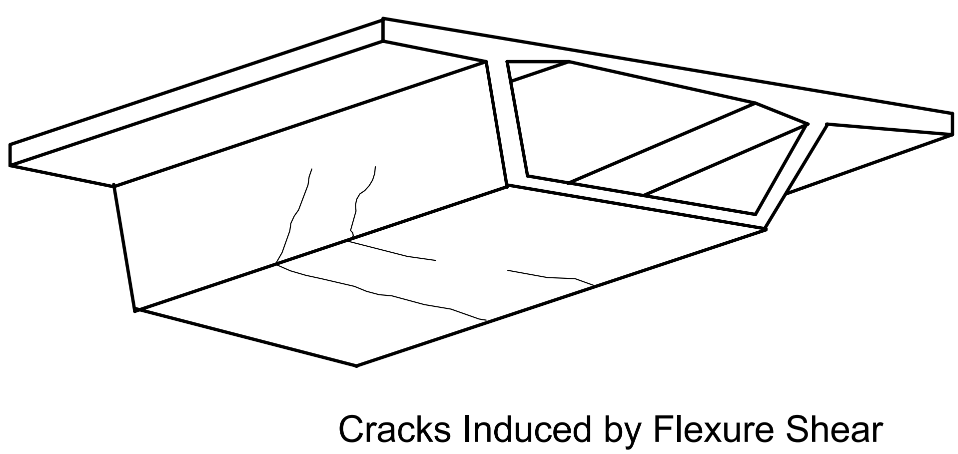


Figure 7.11.36 Box Girder Cracks Induced by Flexure-shear

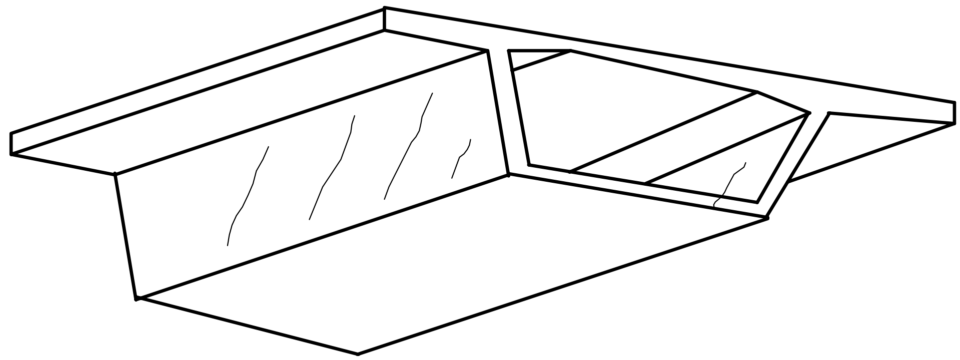


Figure 7.11.37 Box Girder Cracks Induced by Shear

Anchor Blocks

- Segmental construction relies on the tremendous post-tensioning forces to hold the individual segments together, thus forming the superstructure. Inspection of anchor blocks for segmental box girder bridges is the same as for concrete box girder bridges. Additionally, the inspection needs to focus on the box girder webs adjacent to the anchor blocks and look for the development of vertical cracks on either side of the anchors. Examine the condition of the tendons adjacent to the anchor blocks. The slab on which the anchor block is located will require attention concerning the potential for transverse cracking in the vicinity of the anchor (see Figure 7.11.38).

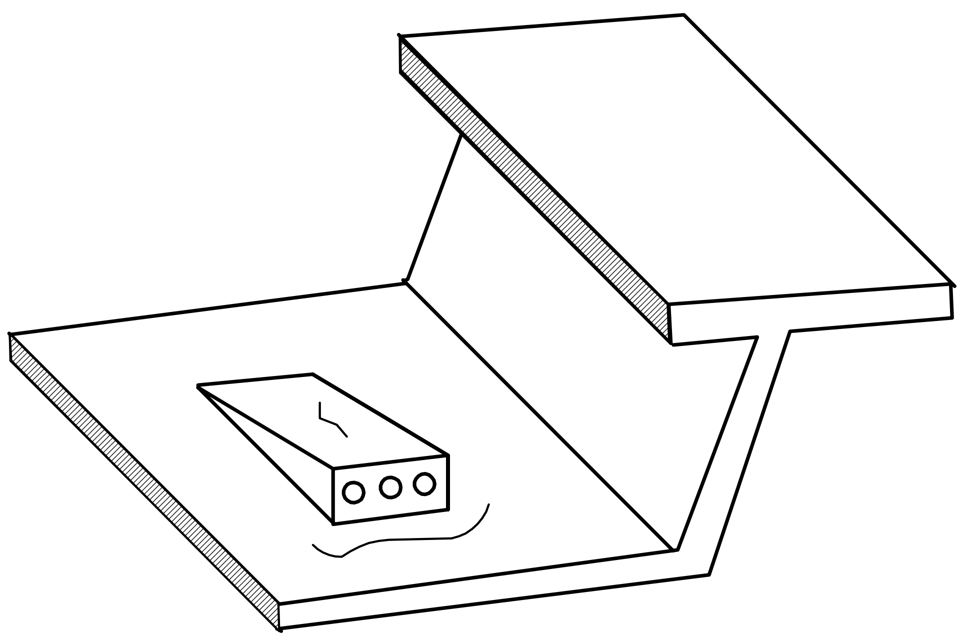


Figure 7.11.38 Box Girder Cracks Adjacent to Anchorage Block

Joints

- Joints should be inspected for crushing and movement of the shear keys (see Figure 7.11.39). The presence of joints opening needs to be documented. Areas where the type of construction required closure joints or segments to be poured in place will need close attention. These areas sometimes are regions of tendon anchorages and couplers. The stress concentrations in these areas are very much different than a section away from the anchorages where a distributed stress pattern exists (see Figure 7.11.40). Additionally, the effects of creep and tendon relaxation are somewhat higher in these regions.

Figure 7.11.39 Close-up View of Box Girder Shear Keys

Figure 7.11.40 View of Box Girder Joint and Anchorage Block

Diaphragms

- The box girder cross section at the abutments and piers is quite different than at any other typical section due to the internal diaphragms. These diaphragms serve to stiffen the box section at these locations and to distribute the large bearing reaction loads. Tendon anchorages located within the diaphragm can also complicate matters. No doubt this region of the structure is very highly stressed and, therefore, prone to crack development. Areas such as this require close examination during inspection (see Figure 7.11.41).

Figure 7.11.41 Box Girder Interior Diaphragm

Areas Exposed to Drainage

- As with any type of crack, the ingress of moisture penetration can lead to corrosion of reinforcing steel and more importantly the highly stressed tendons. Tendon corrosion will eventually result in spalling of the concrete surface due to expanding volume changes of the steel. Focusing again on the tendon itself, moisture will play part in the stress corrosion of the strand and may ultimately lead to its failure.

- When observing a crack, the inspector should also look for other tell tale signs with regards to the extent of cracking. The presence of rust staining or white lime stains is a good indicator that the crack is being subjected to moisture or the passage of water. These distressful signs signal the fact that the crack has propagated to the level of the reinforcing steel or tendon.

- All surfaces of the concrete box girder need to be examined for spalling or its predecessor, delamination. This type of defect could be the result of reactive aggregates within the concrete mix or entrapped water, which has frozen. Again, the spall may be caused by a misaligned tendon located too close to the slab surface. Spalling may be most prevalent in the top slab, which also serves as the traffic surface for the structure. Extreme exposure to the elements of nature as well as deicing chemicals usually leads to the demise of most bridge decks.

Areas Exposed to Traffic

- Inspection of areas over traffic is the same as those for concrete box girder bridges.

Areas Previously Repaired

- Inspection of previous repairs is the same as those for concrete box girder bridges.

Miscellaneous Areas

- Cracks Caused by Torsion **-** This type of cracking will occur in both the slabs and webs of the box girder due to the twisting motion induced into the section. This cracking is very similar to shear cracking and will produce a helical configuration if torsion alone was present. Bridge structures most often will not experience torsion alone; rather bending, shear and torsion will occur simultaneously. In this event, cracking will be more pronounced on one side of the box due to the additive effects of all forces (see Figure 7.11.42).

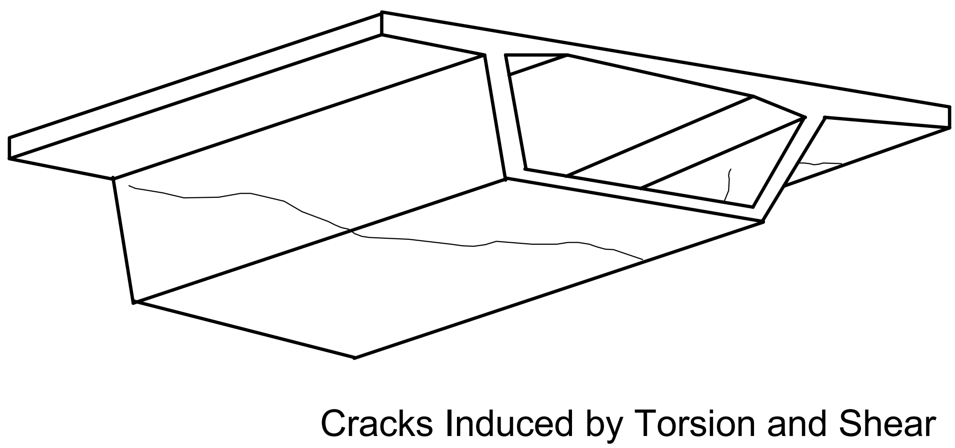


Figure 7.11.42 Box Girder Cracks Induced by Torsion and Shear

- Thermal Effects - The effects of temperature and the appropriate inspection procedures to accommodate for it is the same as those for concrete box girder bridges. Additionally, these cracks can also occur at section element changes in thickness such as that between a web and a slab. In this case the cracking will occur at the juncture between these two elements (see Figure 7.11.43 and 7.11.44).

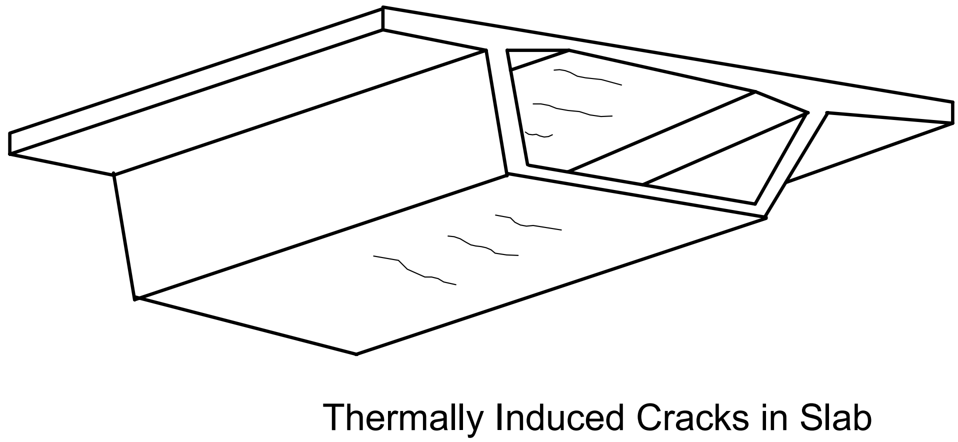


Figure 7.11.43 Thermally Induced Cracks in Box Girder Slab

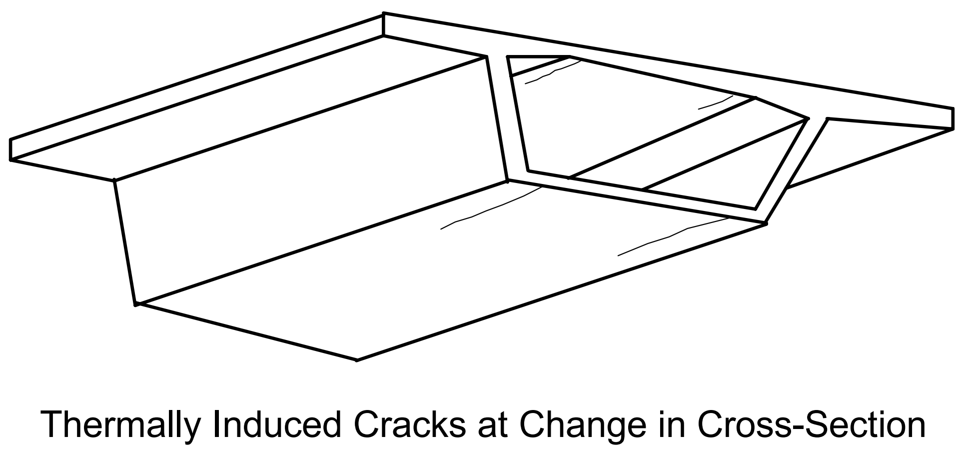


Figure 7.11.44 Thermally Induced Cracks at Change in Box Girder Cross Section

- Cracking Along the Line of Tendons - Cracking can occur along any of the lines of post-tensioning tendons. This is why it is important for the inspector to be aware of the tendon locations within the box girder section. This cracking may be the result of a bent tendon or a misaligned tendon with insufficient concrete cover. Shrinkage of the concrete adjacent to large tendons has also caused this type of cracking.

- Radial Cracking - Post-tensioning tendons can be aligned vertical, horizontal or both depending on the vertical and horizontal geometry of the finished structure. The tendons produce a component of force normal to the curvature of their alignment. The result of this force can be cracking or spalling of the concrete elements that contain these tendons. This type of distress is localized to the tendon in question, but can virtually occur anywhere along the length of the tendon. Joints of match cast precast segments are particularly sensitive to this type of cracking.

- For externally post-tensioned box girders, deviation blocks and blister blocks should be carefully examined for spalling and/or cracking distress due to tendon sleeve misalignment (see Figure 7.11.45). These are points of very high stress concentrations and their integrity is essential to the integrity of span continuity post-tensioning. Locating and mapping areas of spalling and delamination on the top slab is essential because of the structural importance of this element.

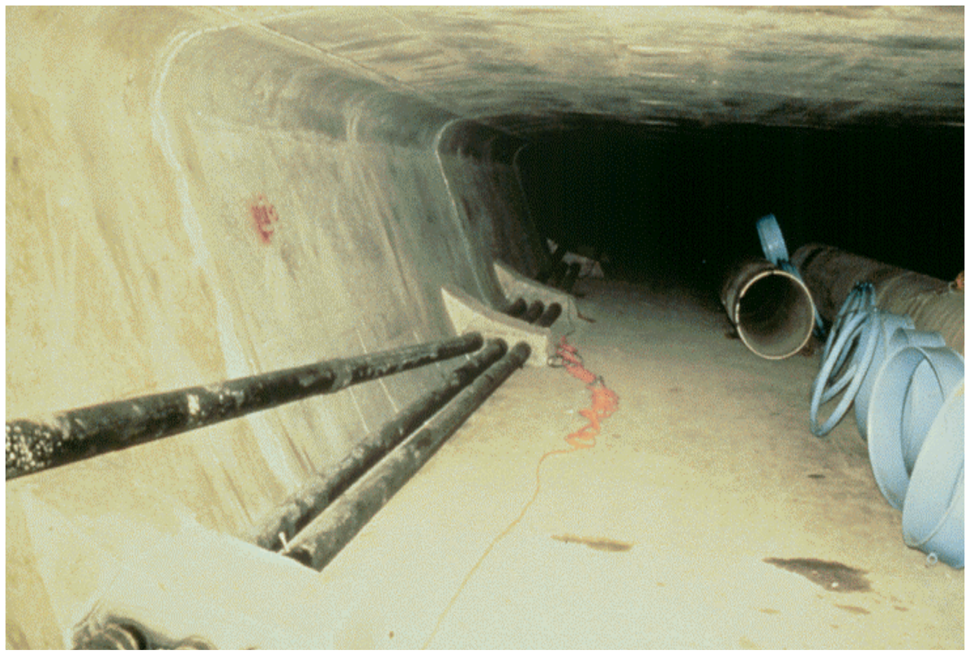


Figure 7.11.45 Inside View of Externally Post-tensioned Box Girder

- Inspection of the roadway surface for cracking, spalling, twisting, and deformation; the presence of these defects can increase the impact effect of traffic; also this may be of great significance since, in many segmental bridges, the top of the structural member is the riding surface

- Investigation of unusual noises, such as banging and screeching, which may be the result of structural distress

- Observation and recording of data from any monitoring instrumentation (e.g., strain gauges, displacement meters, or transducers) that has been installed on or within the bridge

- Check the condition of the drainage holes to see if they are clear and functioning properly.

- Destructive Testing **-** Due to the active nature of the prestressing effect, any destructive testing may seriously alter the structural behavior of a segmental bridge. Therefore, it is important that no cutting or drilling of the concrete box girder be undertaken during the course of the inspection without prior approval of the bridge engineer.

7.11.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete superstructures. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2).

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the superstructure. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element level Smart Flags are also used to describe the condition of the concrete superstructure.

In an element level condition state assessment of a concrete box girder bridge, the AASHTO CoRe element is:

Element No.	Description
104	Prestressed Concrete Closed Web/Box Girder
105	Reinforced Concrete Closed Web/Box Girder

The unit quantity for the girder/beam is meters or feet and the total length of all girders must be placed in one of the four available condition states. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

Table of Contents

Section 7
Inspection and Evaluation of Common Concrete Superstructures

This page intentionally left blank

Topic 7.12 Concrete Box Culverts

7.12.1 Introduction

One of the most common types of culverts used today is the concrete box culvert (see Figure 7.12.1). A box culvert has an integral floor system that supports the side walls and provides a lined channel for the water to flow. The dimensions of the box culvert are determined by the peak flow of the channel. Box culverts are used in a variety of circumstances for both small and large channel openings and are easily adaptable to a wide range of site conditions, including sites that require low profile structures. In situations where the required size of the opening is very large, a multicell box culvert can be used (see Figure 7.12.2). It is important to note that although a box culvert may have multiple barrels, it is still a single structure. The internal walls are provided to reduce the unsupported length of the top slab. Also, there is no distinction between substructure and superstructure, and there is no deck.

Figure 7.12.1 Concrete Box Culvert

Figure 7.12.2 Multicell Concrete Box Culvert

7.12.2 Design Characteristics

Loads on Concrete Box Culverts

There are several basic loads applied in the design of a culvert (see Figure 7.12.3). They are:

- Dead loads (culvert self –weight)
- Vertical earth pressure (weight of earth such as fill and road surface)
- Horizontal (lateral) earth pressure
- Live loads (vehicular traffic, pedestrian traffic)

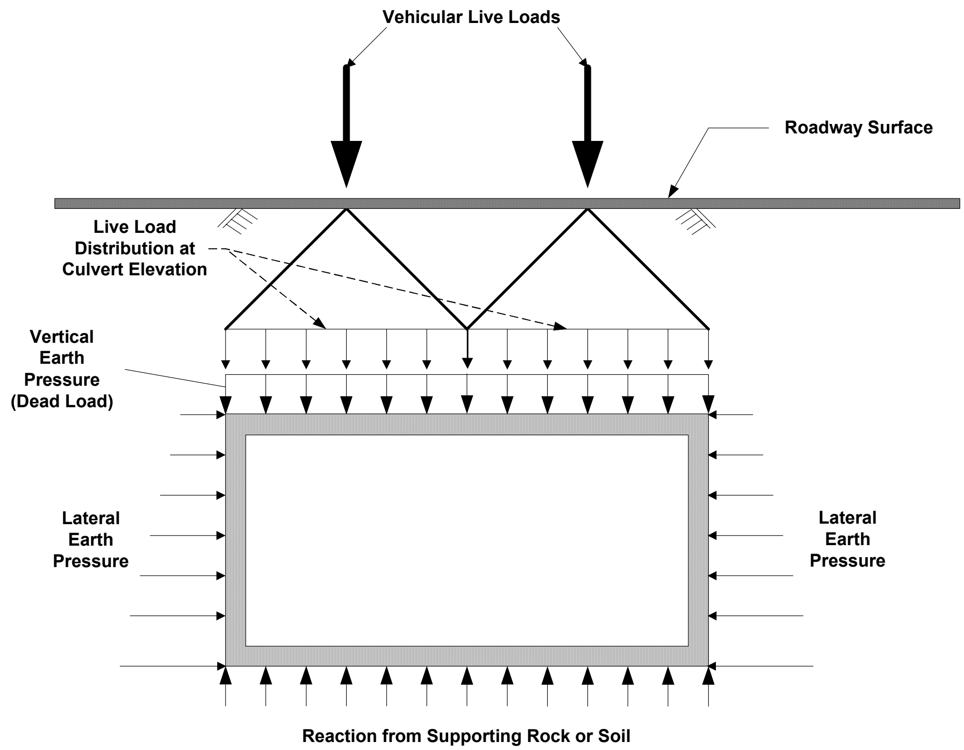


Figure 7.12.3 Loads on a Concrete Box Culvert

For a detailed description of loads on culverts, see Topic P.3.7.

Steel Reinforcement

Primary Reinforcement

The primary reinforcing steel for both precast and cast-in-place box culverts is tension and shear steel. Tension steel is placed transversely in the top and bottom slabs. Shear steel is placed vertically in each of the box walls (see Figure 7.12.4).

Secondary Reinforcement

Temperature and shrinkage reinforcement is also included in the top and bottom slabs and the walls of both cast-in-place and precast box culverts. Ducts are provided in the precast box sections for longitudinal post-tensioning of the boxes with high strength steel strands (see Figure 7.12.5).

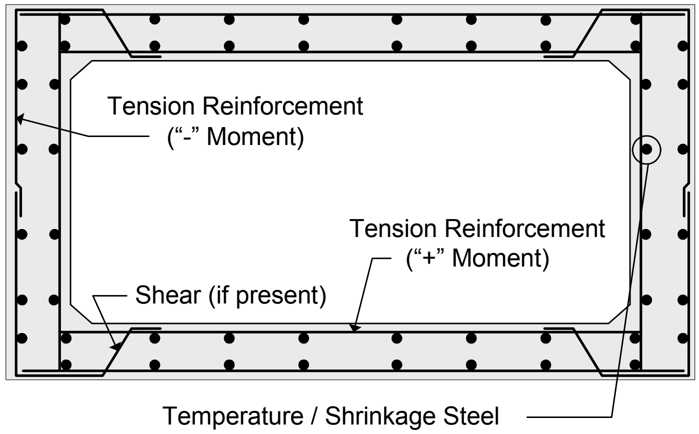


Figure 7.12.4 Steel Reinforcement in a Concrete Box Culvert

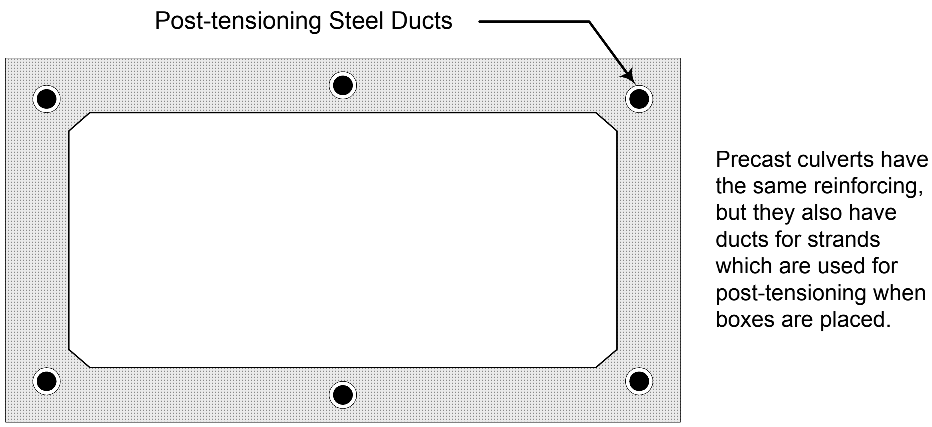


Figure 7.12.5 Precast Box Sections with Post-tensioning Steel

7.12.3 Types of Box Culverts

There are two basic types of concrete box culverts – cast-in-place and precast. Several factors, such as span length, vertical clearance, peak stream flow, and terrain, determine which type of box culvert is used.

Cast-in-Place

Reinforced cast-in-place (CIP) concrete culverts are typically rectangular (box) shaped. The rectangular shape is usually constructed with multiple cells (barrels) to accommodate longer spans. The major advantage of cast-in-place construction is that the culvert can be designed to meet the specific geometric requirements of the site.

Precast

Precast concrete box culverts are designed for various depths of cover and various live loads and are manufactured in a wide range of sizes. Standard box sections are available with spans as large as 3.7 meters (12 feet). Some box sections may have spans of up to 6.1 meters (20 feet) if a special design is used.

See Figure 7.12.10 for the different standard sizes of precast concrete box culverts.

Figure 7.12.6 Precast Concrete Box Culvert

7.12.4 Overview of Common Defects

Common defects that occur in concrete box culverts include:

- Cracking
- Spalling
- Delaminations
- Scaling
- Honeycombs
- Pop-outs
- Abrasion
- Wear
- Overload damage
- Efflorescence
- Section loss of exposed reinforcing bars
- Embankment scour at culvert inlet and outlet
- Roadway settlement

Refer to Topic 2.2 for a more detailed explanation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

7.12.5 Inspection Procedures and Locations

Safety is the most important reason that culverts should be inspected. For a more detailed discussion on reasons for inspecting culverts, see Topic P.3.1.

Previous inspection reports and as-built plans, when available, should be reviewed prior to, and possibly during, the field inspection. A review of previous reports will familiarize the inspector with the structure and make detection of changed conditions easier. A review will also indicate critical areas that need special attention and the possible need for special equipment.

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection will be conducted. In addition to the culvert components, the inspector should also look for highwater marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

For typical installations, it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and inspection of the approach roadway. The inspector should select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. The inspector should then move to the other end of the culvert. The following sequence is applicable to all culvert inspections:

- Review available information
- Observe overall condition
- Inspect approach roadway and embankment
- Inspect waterway (see Topic 11.2)
- Inspect end treatments
- Inspect culvert barrel

Procedures

Visual

The inspection of concrete for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

Hammer sounding of the exposed concrete should be performed.

If the inspector deems it necessary, core samples can be taken and sent to a laboratory to determine the extent of any chloride contamination.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

The following is a list of areas that should be inspected in box culverts.

- Misalignment
- Joint defects
- Cracks and spalls
- Contact surfaces
- Weep holes

Misalignment

The vertical and horizontal alignment should be checked by visual observation. Vertical alignment should be checked for sags, faulting, or differential settlement at joints. Sags can best be detected during low flows by looking for areas where the water is deeper or where sediment has been deposited. When excessive accumulations of sediment are present, it may be necessary to have the sediment removed before checking for sags. An alternate method would be to take profile elevations of the top slab. The horizontal alignment can be checked by sighting along the walls and by examining joints for differential movement (see Figure 7.12.7).

Figure 7.12.7 Sighting Along Culvert Sidewall to Check Horizontal Alignment

Joint Defects

Expansion joints should be carefully inspected to verify that the filler material or joint sealant is in place and that the joint is not filled with incompressible material that would prohibit expansion. Spalls or cracks along joint edges are usually an indication that the expansion joint is full of incompressible materials or that one or more expansion joints are not working. Joint inspection also should identify any joints that are opened widely or are not open to uniform width. Water flowing or seeping into the culvert through open joints (infiltration) may bring with it supporting soil. Water flowing out of the culvert through open joints (exfiltration) may cause erosion of supporting material.

Figure 7.12.8 Precast Concrete Box Culvert Joint

Cracks and Spalls

The top slab and walls should be inspected visually for cracks and spalls. When either is observed, the area around the defect should be tapped with a hammer to detect incipient spalls. A ladder may be needed for inspecting the top slab. Longitudinal cracks (along the length of the culvert) in the top slab of box culverts may indicate either flexure or shear problems. Transverse cracks may indicate differential settlement. Longitudinal cracks may also indicate differential wall settlement, or structural overloading. Transverse cracks (along the span length) indicate differential settlement of culvert sections. Spalls may occur along the edges of cracks or in the concrete covering corroded reinforcing steel. Cracks in the sides may be caused by settlement or earth pressure. The location, size, and length or area of all cracks and spalls should be noted in the inspection report.

Figure 7.12.9 Cast in Place Concrete Box Culvert Outlet

Figure 7.12.10 Spalls and Delaminations

Contact Surfaces

The concrete surfaces exposed to stream flow should be checked by visual inspection and by tapping with a hammer for unsound concrete due to chemical attack or abrasion. The bottom of the top slab, the invert slab, and the water line on the walls are the most likely areas to be damaged.

Weep Hole

Weep holes are often provided on the sidewalls and wingwalls to drain water from the backfill and reduce the hydraulic pressure on the sidewalls. Weep holes should be inspected to determine if they are functioning properly. Lack of flow during periods when flow has previously been observed may indicate blockage. Fines in the floor also indicate improper functioning.

7.12.6 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete box culverts. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the culvert (Item 62). This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. Rating codes range from 9 to 0, where 9 is the best rating possible (see Topic 4.2). The rating code is intended to be an overall evaluation of the culvert. Integral wingwalls to the first construction or expansion joint should be included in the evaluation. It is also important to note that Items 58-Deck, 59-Superstructure, and 60-Substructure should be coded “N” for all culverts.

General NBI bridge rating guidelines are applicable but are supplemented by NBI guidelines created for culvert structures as well as the specific concrete box culvert rating guidelines shown in Figure 7.12.9. The final culvert component rating assigned should accurately reflect all three guidelines.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

In an element level condition state assessment of a concrete box culvert, the AASHTO CoRe element is:

Element No.	Description
241	Reinforced Concrete Culvert

The quantity unit for culverts is meters or feet of culvert length along the barrel. The total quantity equals the culvert length times the number of barrels. The inspector must visually evaluate each 1 m (1 ft) slice of the culvert barrel(s) and assign the appropriate condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements condition state assessment method for condition state descriptions.

The condition state descriptions for each slice are then compiled such that the total quantity of culvert is described by various quantities of culvert length distributed over a range of four condition state descriptions. The sum of the individual condition state quantities must equal the total element quantity.

RATING GUIDELINES FOR CAST-IN-PLACE CONCRETE CULVERT BARRELS

RATING	CONDITION	RATING	CONDITION
9	• New condition	4	• Alignment: marginal; significant settlement and misalignment; evidence of piping • Joints: differential movement and separation of joints, significant infiltration or exfiltration at joints • Concrete: extensive cracking with cracks open more than 0.12 in. with efflorescence; spalling has caused exposure of rebars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in. • Footings: scour along footing with slight undermining, protection required
8	• Alignment: good, no settlement or misalignment • Joints: tight with no defects apparent • Concrete: no cracking, spalling, or scaling present; surface in good condition • Footings: good with no invert scour	3	• Alignment: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • Joints: significant openings and differential movement; infiltration or exfiltration causing misalignment of culvert and settlement or depressions in roadway • Concrete: extensive cracking with spalling, delaminations, and slight differential movement; scaling has exposed reinforcing steel in bottom of top slab or invert • Footings: severe undermining with slight differential settlement causing minor cracking or spalling in footing and walls
7	• Alignment: generally good; minor misalignment at joints; no settlement • Joints: joint material deteriorated at isolated locations • Concrete: minor hairline cracking at isolated locations; slight spalling or scaling present on invert or bottom of top slab • Footings: good with only minor invert scour	2	• Alignment: critical; culvert not functioning due to severe misalignment • Concrete: severe cracks with significant differential movement; concrete completely deteriorated in isolated locations in top slab or invert • Footings: severe undermining with significant differential settlement causing severe cracks
6	• Alignment: fair, minor misalignment and settlement at isolated locations • Joints: joint material generally deteriorated, minor separation, possible infiltration or exfiltration; minor cracking or spalling at joints allowing exfiltration • Concrete: extensive hairline cracks, some with minor delaminations; scaling less than 0.25 in. deep or small spalls present on invert or bottom of top slab • Footings: minor scour near footings	1	• Culvert: partially collapsed • Road: closed to traffic • Footings: severe undermining resulting in partial collapse of structure
5	• Alignment: generally fair; minor misalignment or settlement; possible piping • Joints: open and allowing backfill to infiltrate; significant cracking or spalling at joints • Concrete: cracking open greater than 0.12 in.; significant delamination and moderate spalling exposing reinforcing steel; large areas of surface scaling greater than 0.25 in. deep • Footings: moderate scour along footing; protective measures may be required	0	• Culvert: total failure of culvert and fill • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 7.12.11 Condition Rating Guidelines

Dimensions and Approximate Weights of Concrete Box Sections

*ASTM C 789 – Precast Reinforced Concrete Box Sections						
		Thickness (in.)			**Waterway Area (Sq. Feet)**	**Approx. Weight (lbs / ft)**
Span (Ft.)	**Rise (Ft.)**	**Top Slab**	**Bot. Slab**	**Wall**		
3	2	4	4	4	5.8	600
3	3	4	4	4	8.8	700
4	2	5	5	5	7.7	910
4	3	5	5	5	11.7	1030
4	4	5	5	5	15.7	1160
5	3	6	6	6	14.5	1430
5	4	6	6	6	19.5	1580
5	5	6	6	6	24.5	1730
6	3	7	7	7	17.3	1880
6	4	7	7	7	23.3	2060
6	5	7	7	7	29.3	2230
6	6	7	7	7	35.3	2410
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.3	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
8	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

* For description of ASTM C 789 see page 7.12.15

Figure 7.12.12 Standard Sized for Concrete Pipe (Source: American Concrete Pipe Association)

Dimensions and Approximate Weights of Concrete Box Sections (continued)

*ASTM C 850 – Precast Reinforced Concrete Box Sections						
Span (Ft.)	Rise (Ft.)	Thickness (in.) Top Slab	Thickness (in.) Bot. Slab	Thickness (in.) Wall	Waterway Area (Sq. Feet)	Approx. Weight (lbs / ft)
3	2	7	6	4	5.8	830
3	3	7	6	4	8.8	930
4	2	7 ½	6	5	7.7	1120
4	3	7 ½	6	5	11.7	1240
4	4	7 ½	6	5	15.7	1370
5	3	8	7	6	14.5	1650
5	4	8	7	6	19.5	1800
5	5	8	7	6	24.5	1950
6	3	8	7	7	17.3	1970
6	4	8	7	7	23.3	2150
6	5	8	7	7	29.3	2320
6	6	8	7	7	35.3	2500
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.1	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
9	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

* For description of ASTM C 850see page 7.12.15

Figure 7.12.12 Standard Sized for Concrete Pipe (Source: American Concrete Pipe Association), continued

ASTM C 789 Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers: Covers box sections with 2 or more feet of earth cover when subjected to highway live loads, and zero cover or greater when subjected to only dead load, to be used for the conveyance of sewage, industrial waste, and storm water, and for the construction of culverts in sizes from 3 foot span by 2 foot rise to 12 foot span by 12 foot rise.

ASTM C 850 Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers with less than 2 feet of Cover Subjected to Highway Loadings: Covers box sections with less than 2 feet of earth cover for the conveyance of sewage, industrial waste, and storm water, and for the construction of culverts in sizes from 3 foot span by 2 foot rise by 12 foot span by 12 foot rise.

This page intentionally left blank